Sensor Characterisation with Darks

Merlin Fisher–Levine
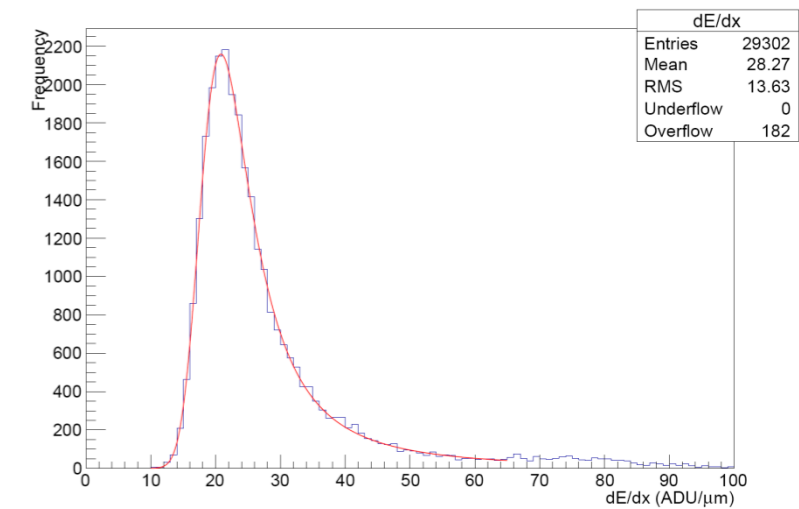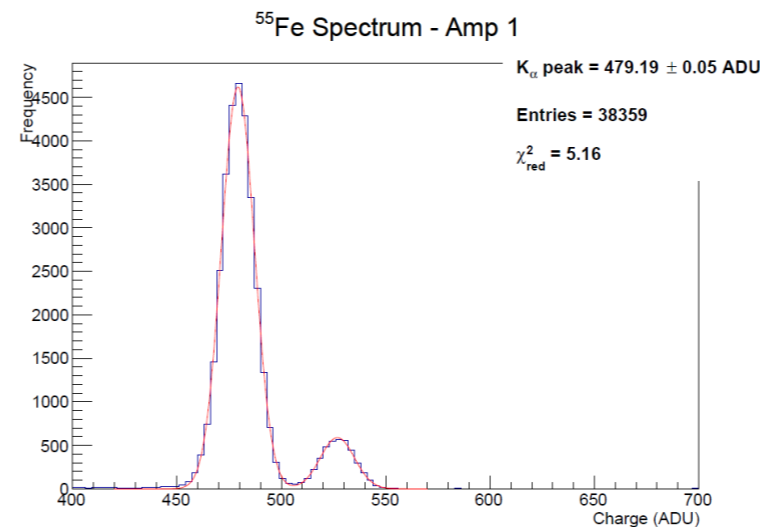
September 2014

Sensor characterisation
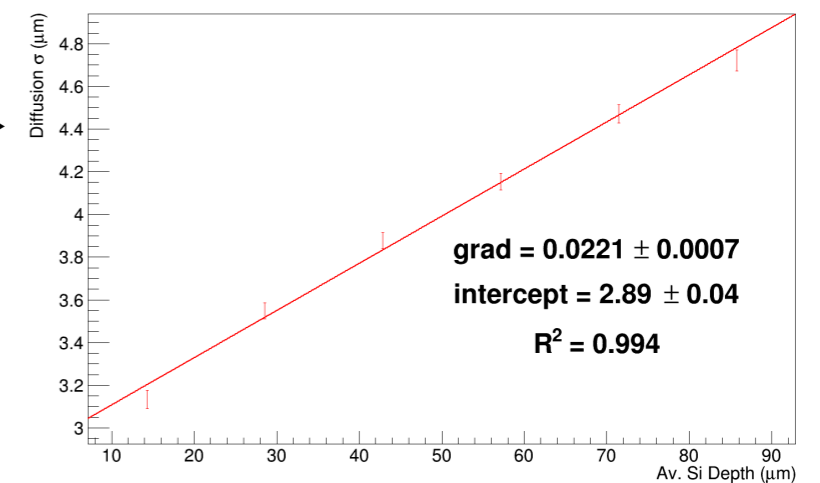
‣ Using dark exposures to characterise LSST sensors

‣ Measuring:

   ‣ Gain

   ‣ Diffusion

   ‣ Edge effects (track bending)

‣ Have been using LSST's DMStack for processing images

   ‣ With further analysis in python and ROOT (sorry)

^{55}Fe Spectrum - Amp 1

K_α peak = 479.19 $\pm$ 0.05 ADU

Entries = 38359

χ^2_{red} = 5.16

dE/dx	
Entries	29302
Mean	28.27
RMS	13.63
Underflow	0
Overflow	182

grad = 0.0221 $\pm$ 0.0007

intercept = 2.89 $\pm$ 0.04

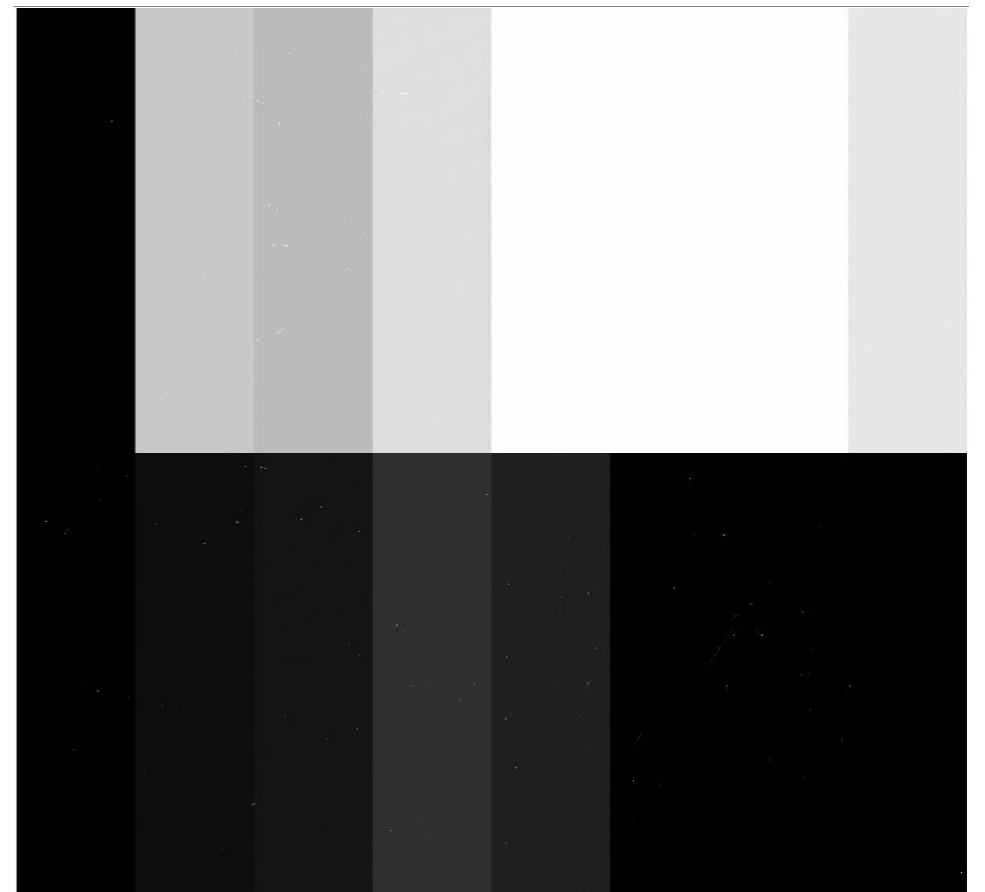R^2 = 0.994

DECAM

LSST

Image assembly

- Image assembled from 16 amplifier sections

- Different ADC offsets cause large background 'brightness' variation

- Subtract these offsets to produce flat image

Image assembly

‣ Image assembled from 16 amplifier sections

‣ Different ADC offsets cause large background 'brightness' variation

‣ Subtract these offsets to produce flat image
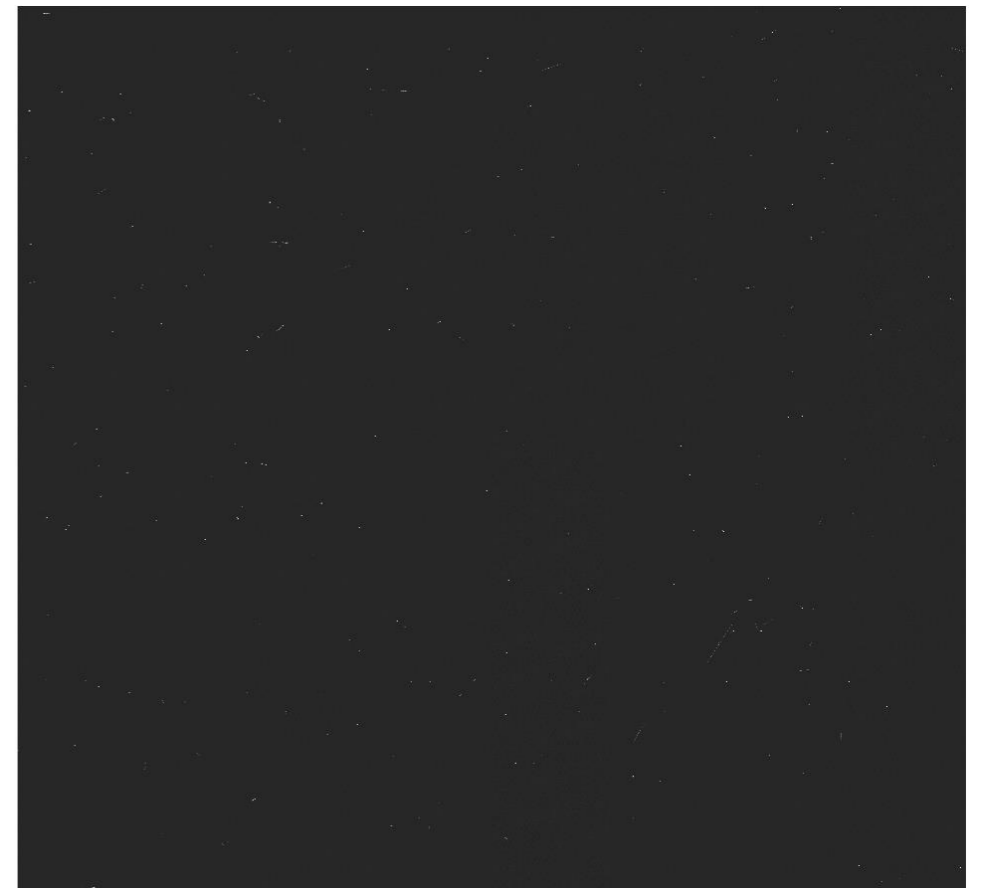
Image assembly

‣ Image assembled from 16 amplifier sections

‣ Different ADC offsets cause large background 'brightness' variation

‣ Subtract these offsets to produce flat image

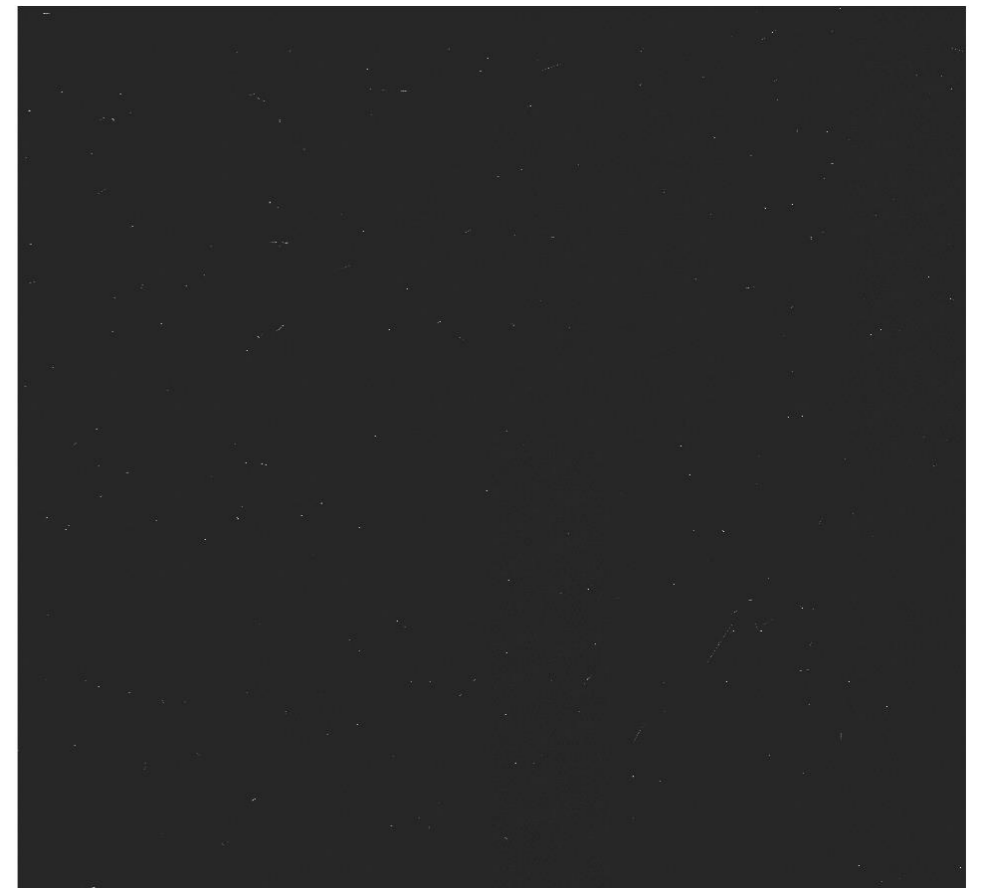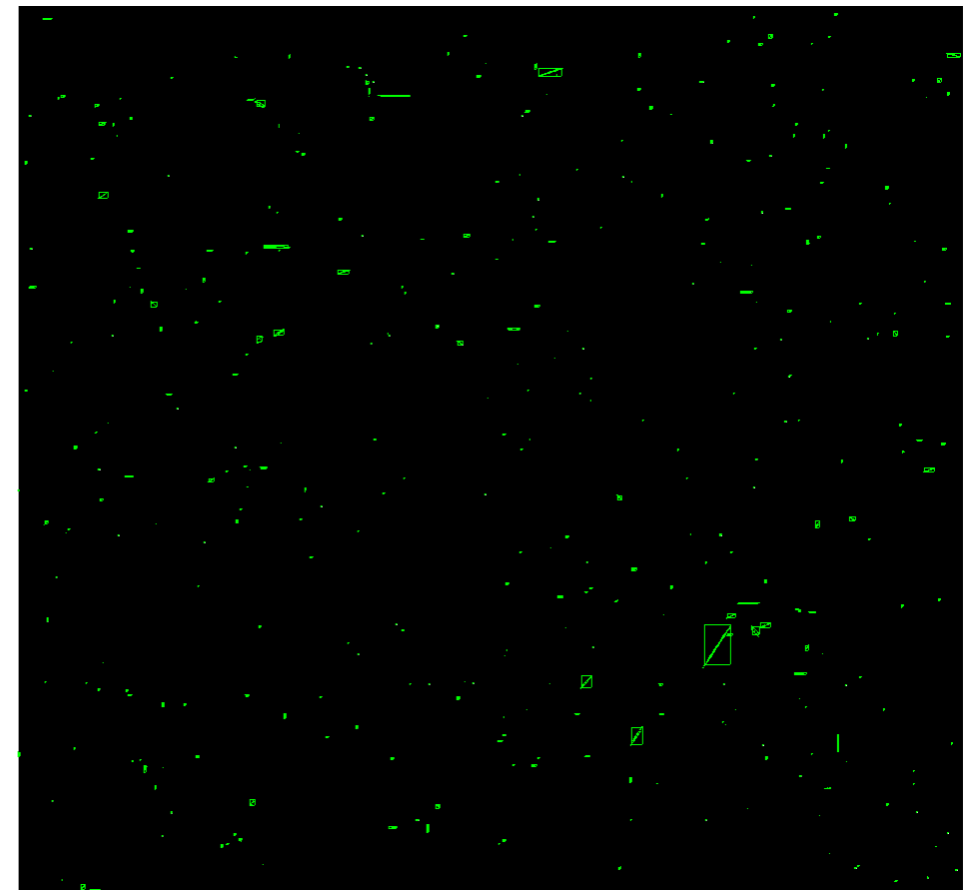‣ Now use DMStack to find tracks in dark exposure

09/08/2014

Image assembly

‣ Image assembled from 16 amplifier sections

‣ Different ADC offsets cause large background 'brightness' variation

‣ Subtract these offsets to produce flat image

‣ Now use DMStack to find tracks in dark exposure

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Track analysis for gain measurement

‣ Each tracks falls into 1 of 3 categories:
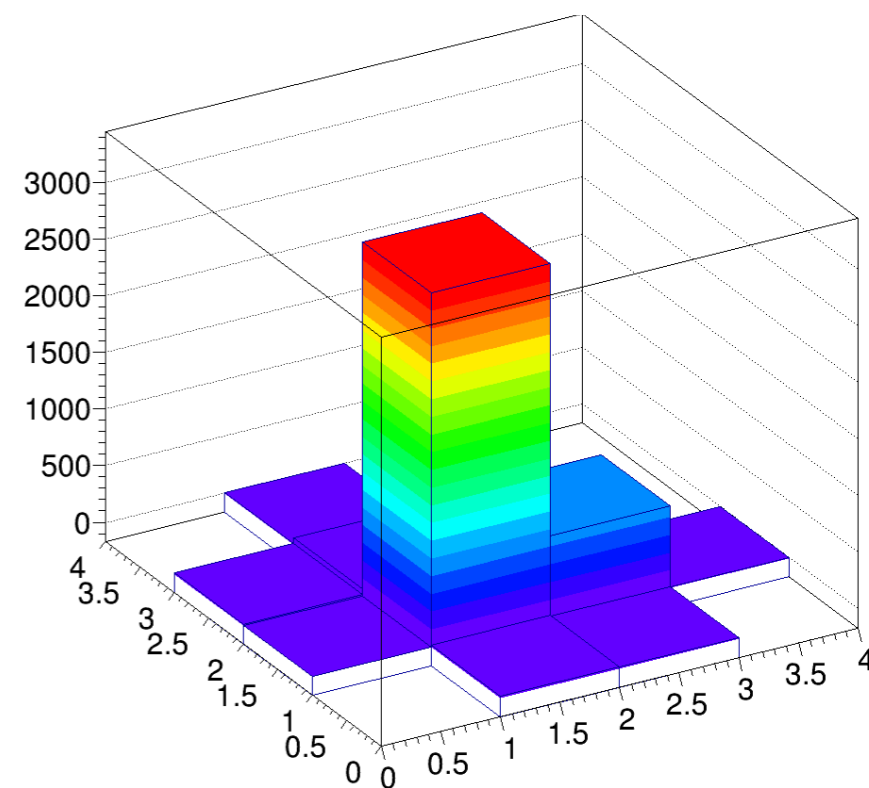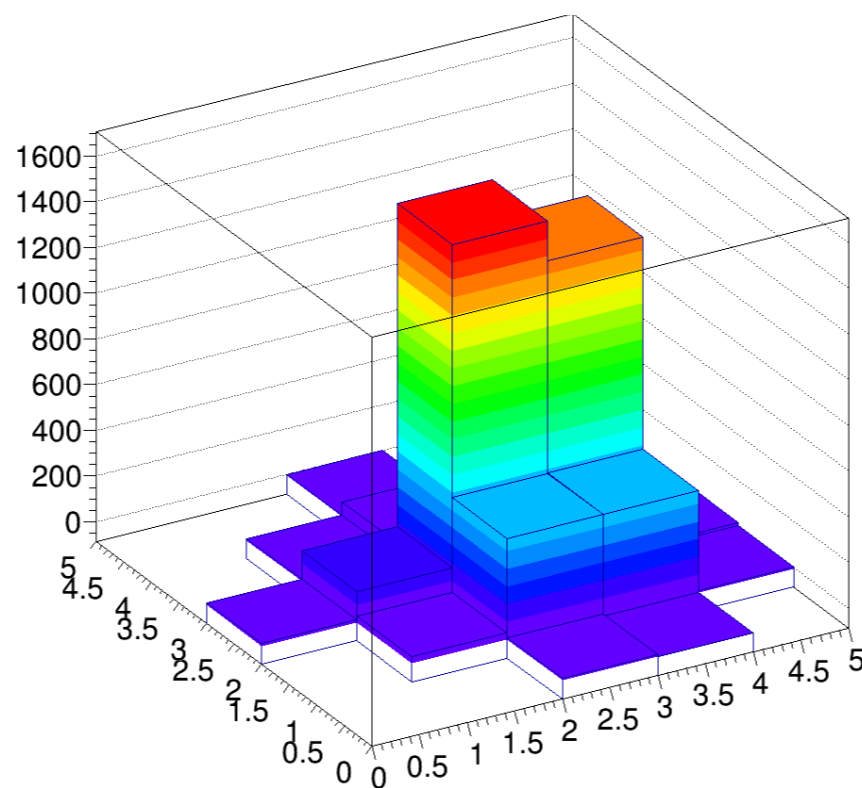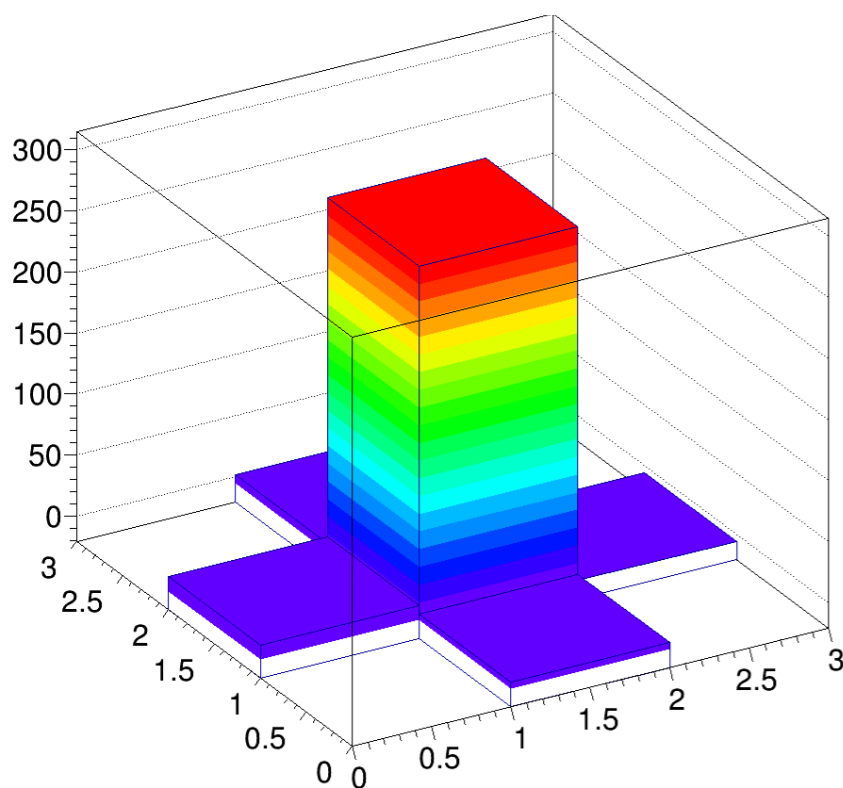 ‣ Worms ⎤
  ‣ Spots ⎦ Soft gammas – not useful – discard
  ‣ <u>Cosmic ray muons</u> ⟵ Useful, keep!

‣ Cosmics ray muons are "minimum ionising particles"
  ‣ Energy per unit length is "constant" and well defined
  ‣ Stochastic mechanism but has a well known distribution
    ‣ Landau distributed energy loss

‣ Want to reject worms and spots, keeping cosmics…

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‣ Find all tracks in dataset

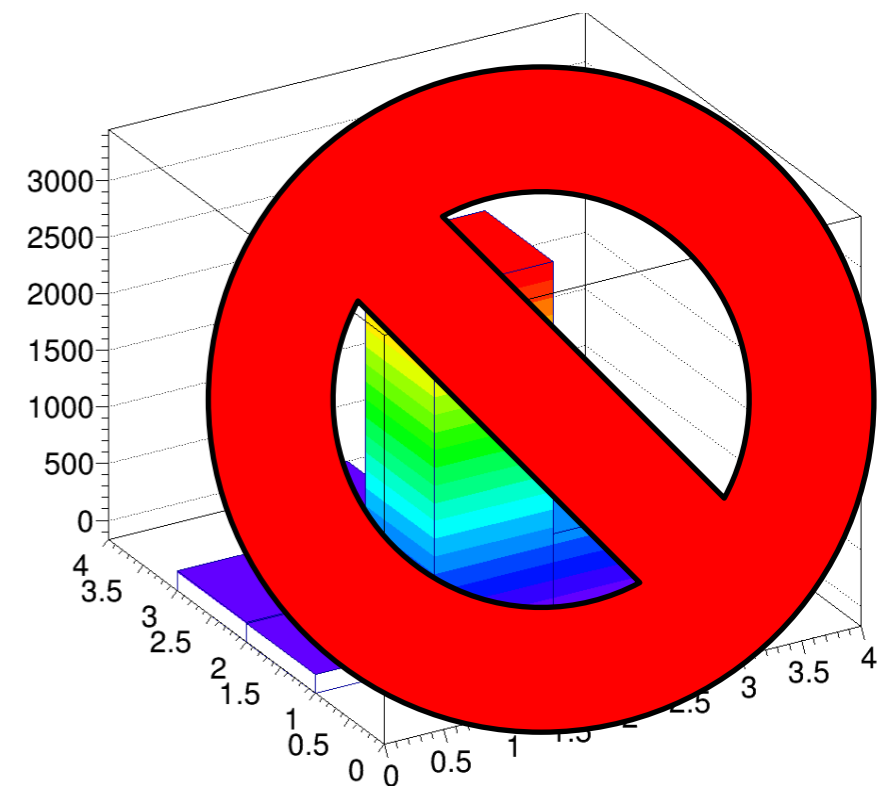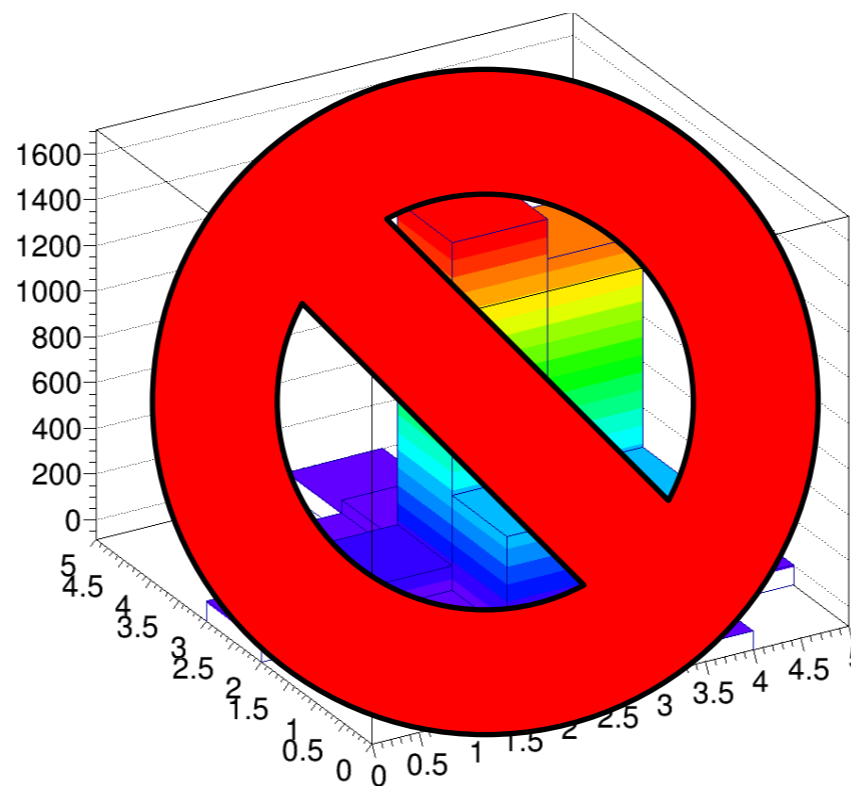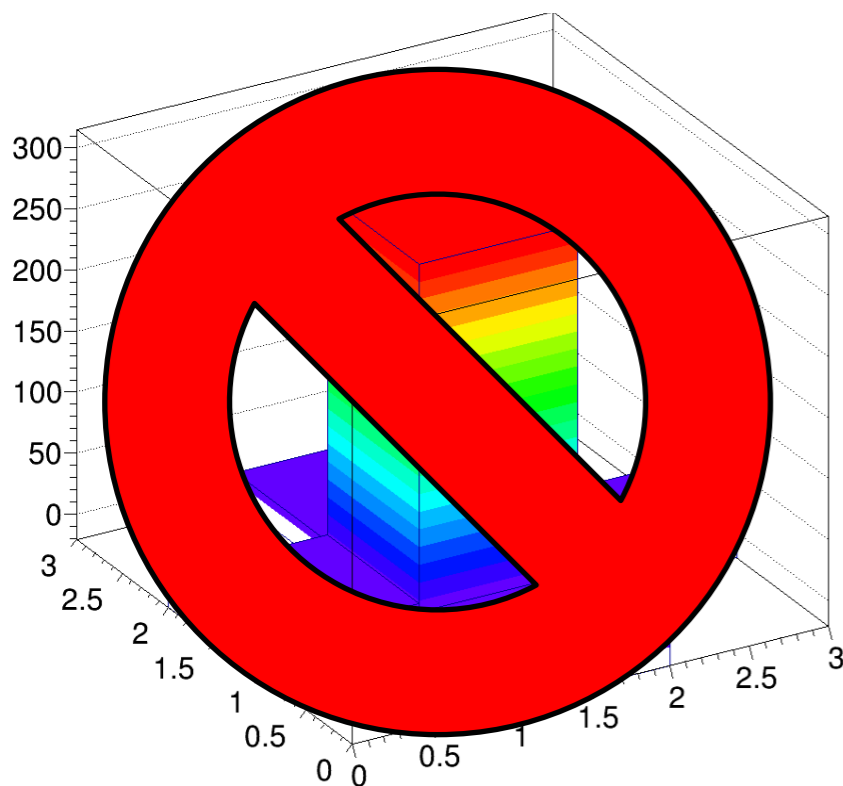   ‣ Cut dataset to only include long & straight tracks

Remove spots

Track cleaning

‣ Find all tracks in dataset

  ‣ Cut dataset to only include long & straight tracks

Remove spots

Track cleaning

‣ Find all tracks in dataset

  ‣ Cut dataset to only include long & straight tracks
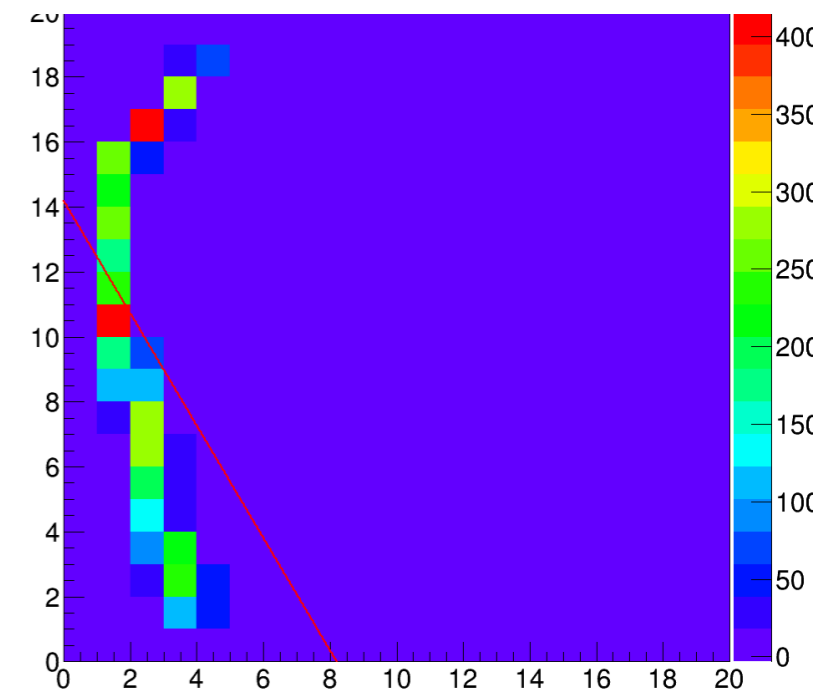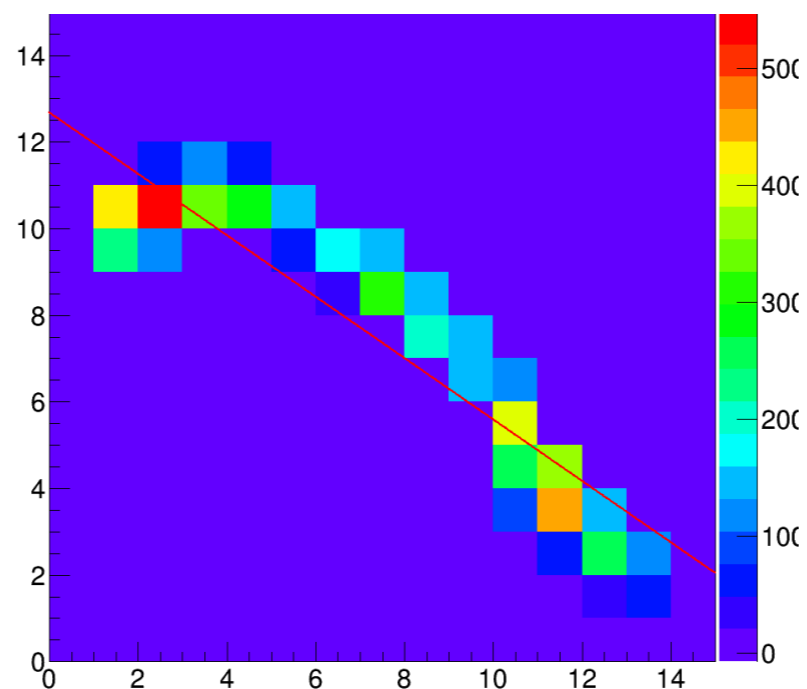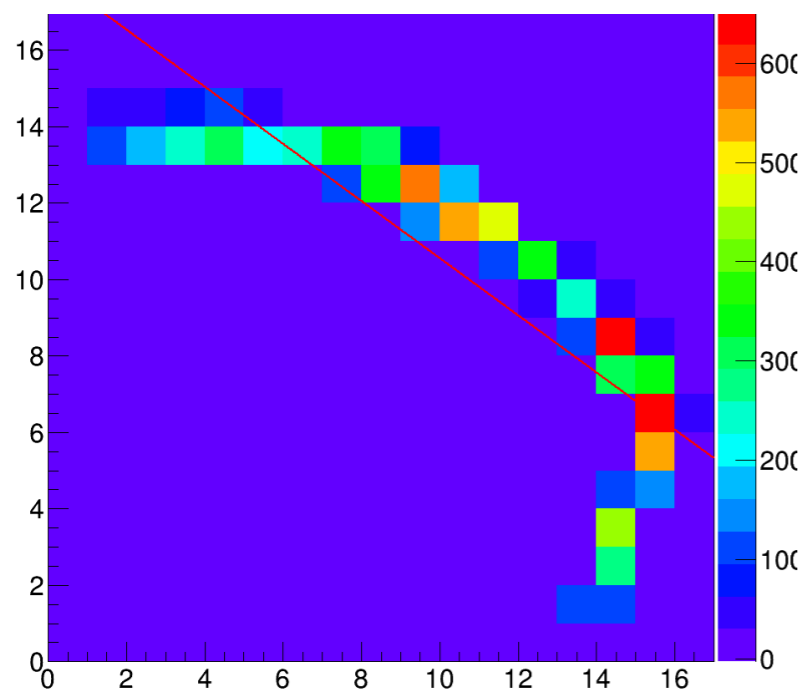
Remove worms

Track cleaning

‣ Find all tracks in dataset

    ‣ Cut dataset to only include long & straight tracks
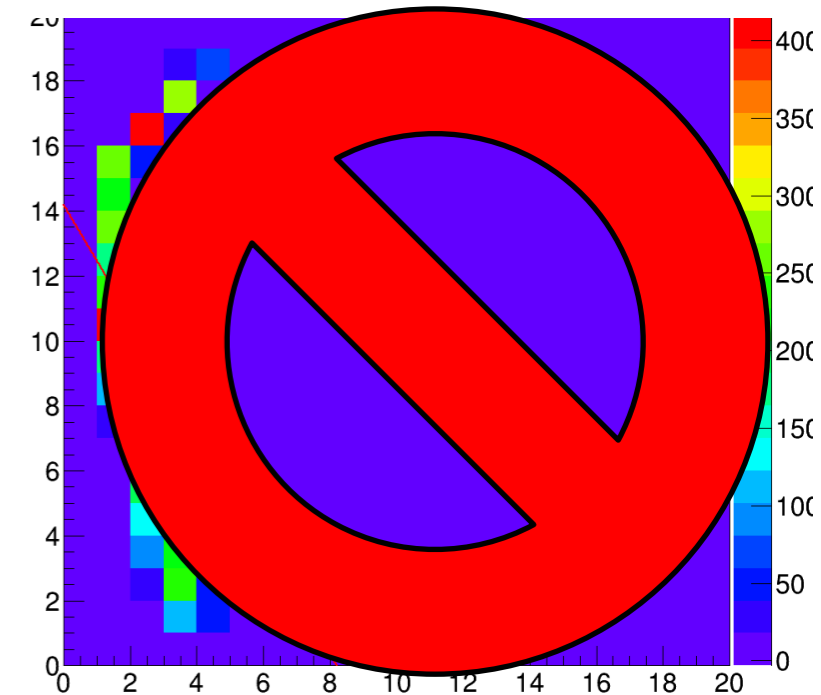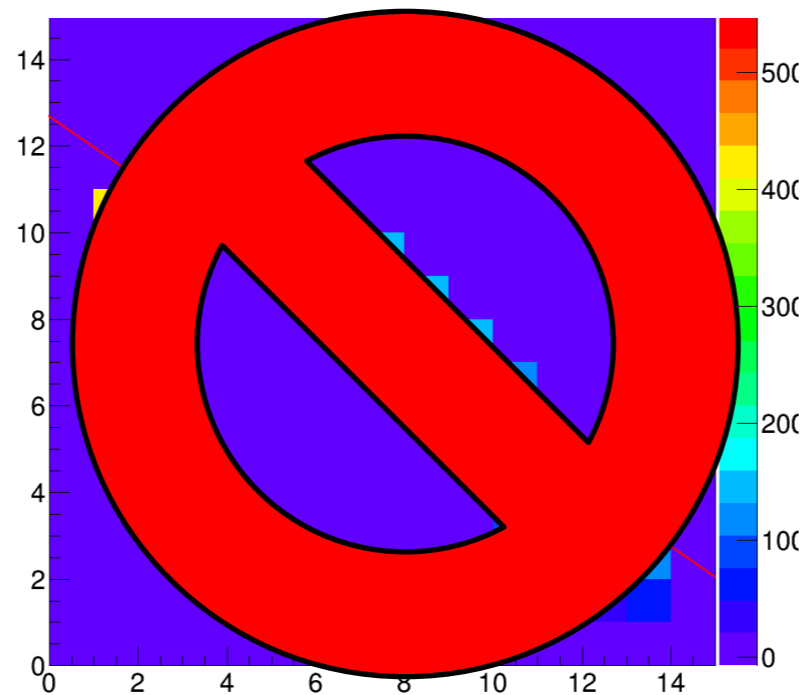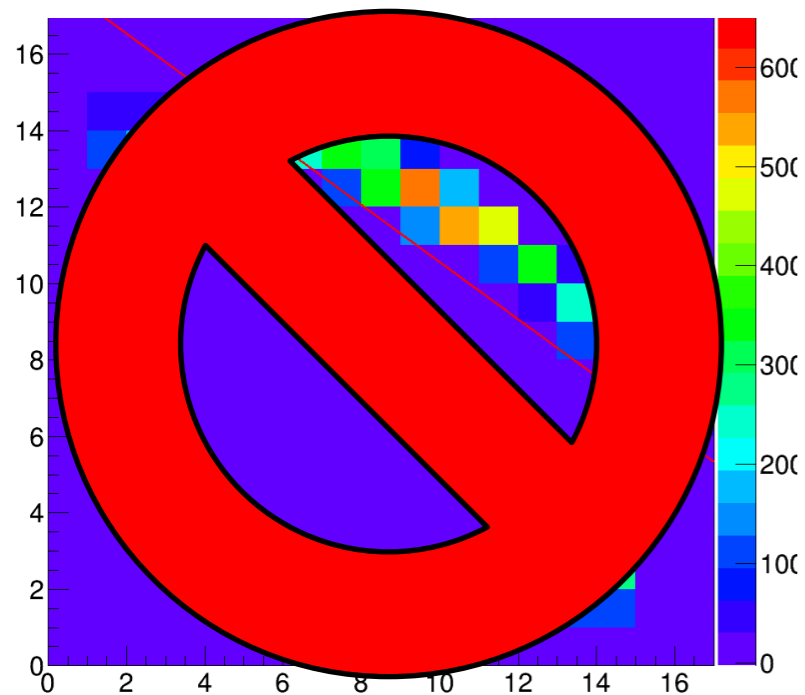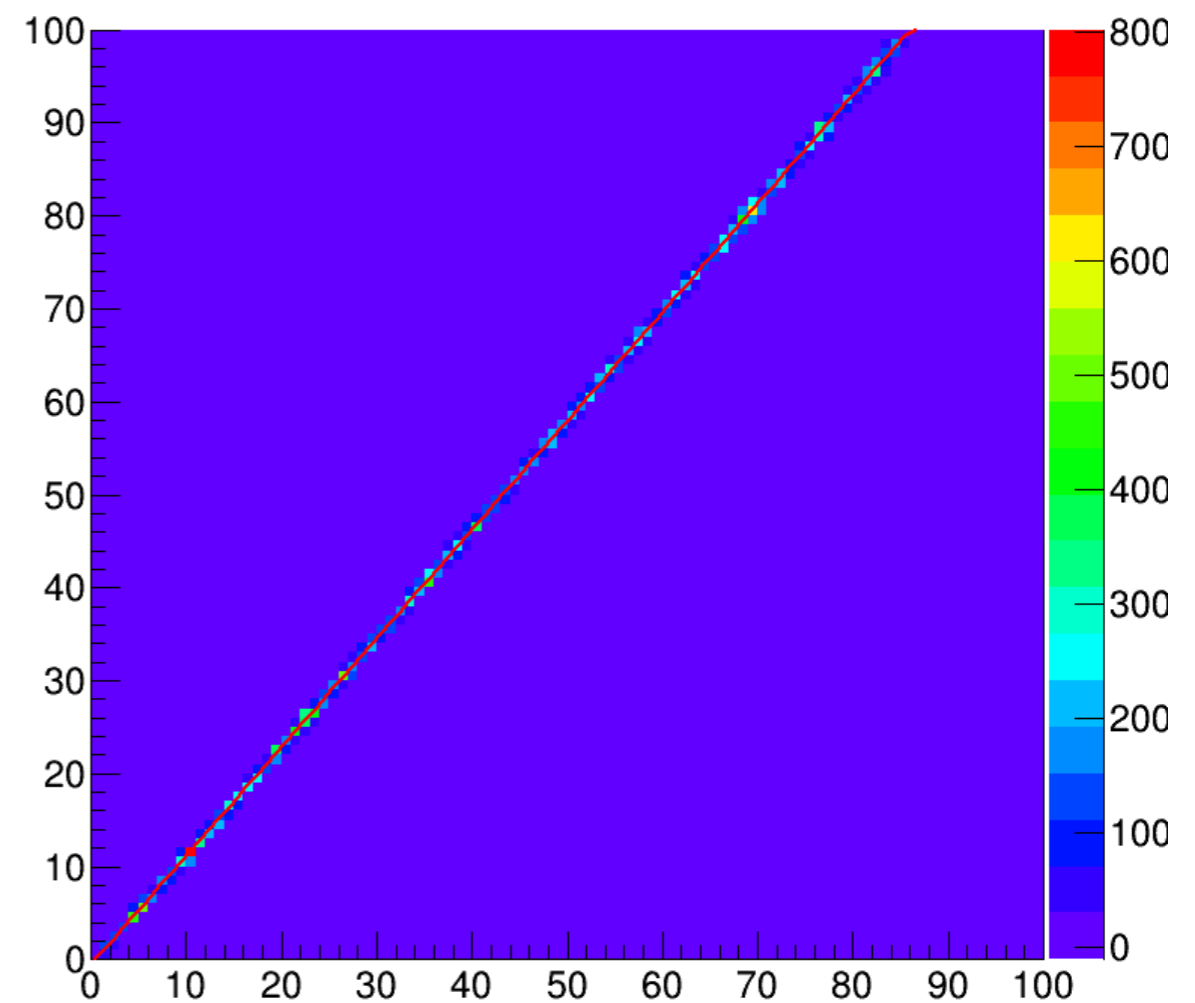
Remove worms

Track cleaning

‣ Dataset now only contains long straight tracks:
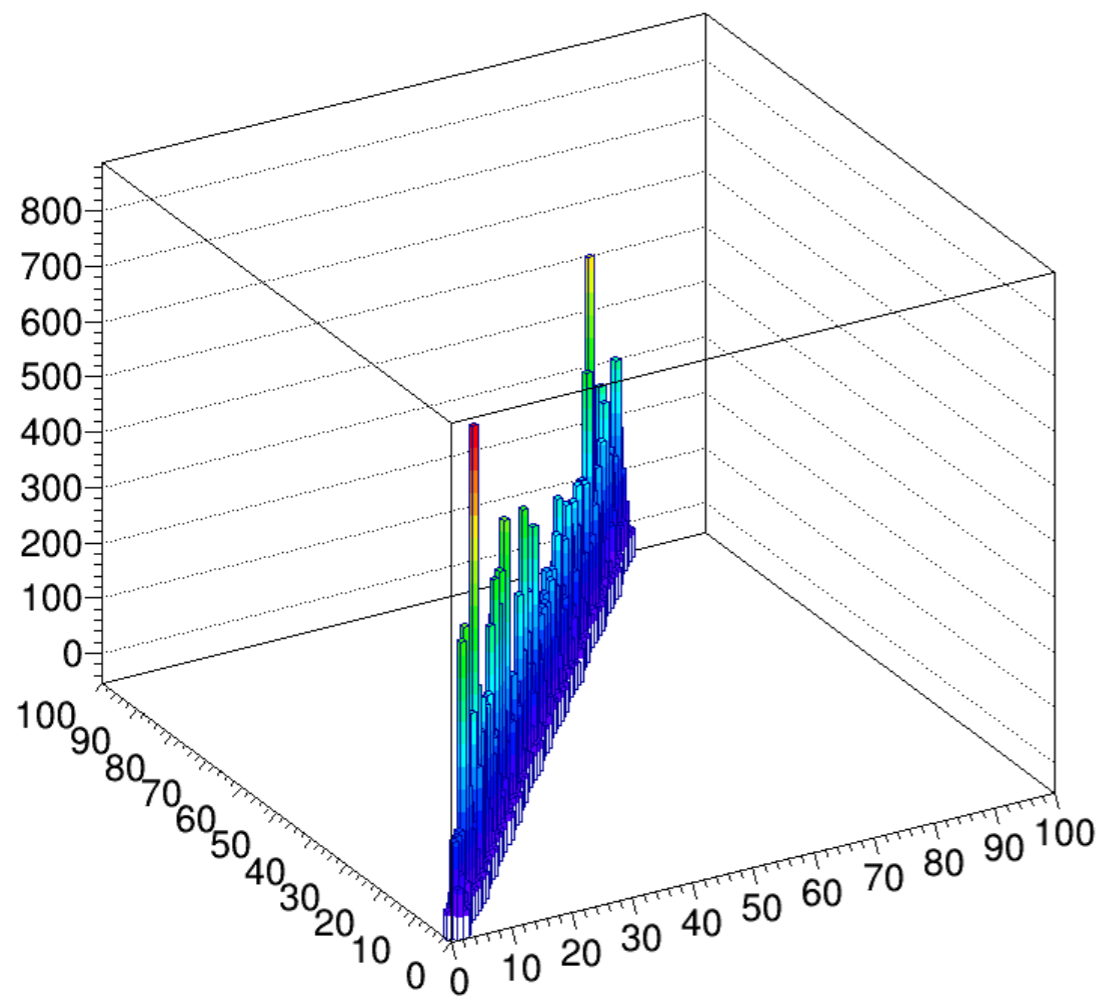
Track cleaning

‣ **Track length distribution:**

   ‣ Defined by sensor thickness & orientation, combined with the angular distribution of cosmic ray muons

   ‣ V. short tracks are due to spots and worms

Track Length	
Entries	66489
Mean	184.6
RMS	118.7
Underflow	0
Overflow	598

Track cleaning

‣ Rejecting worms and spots, sum the total flux in each track
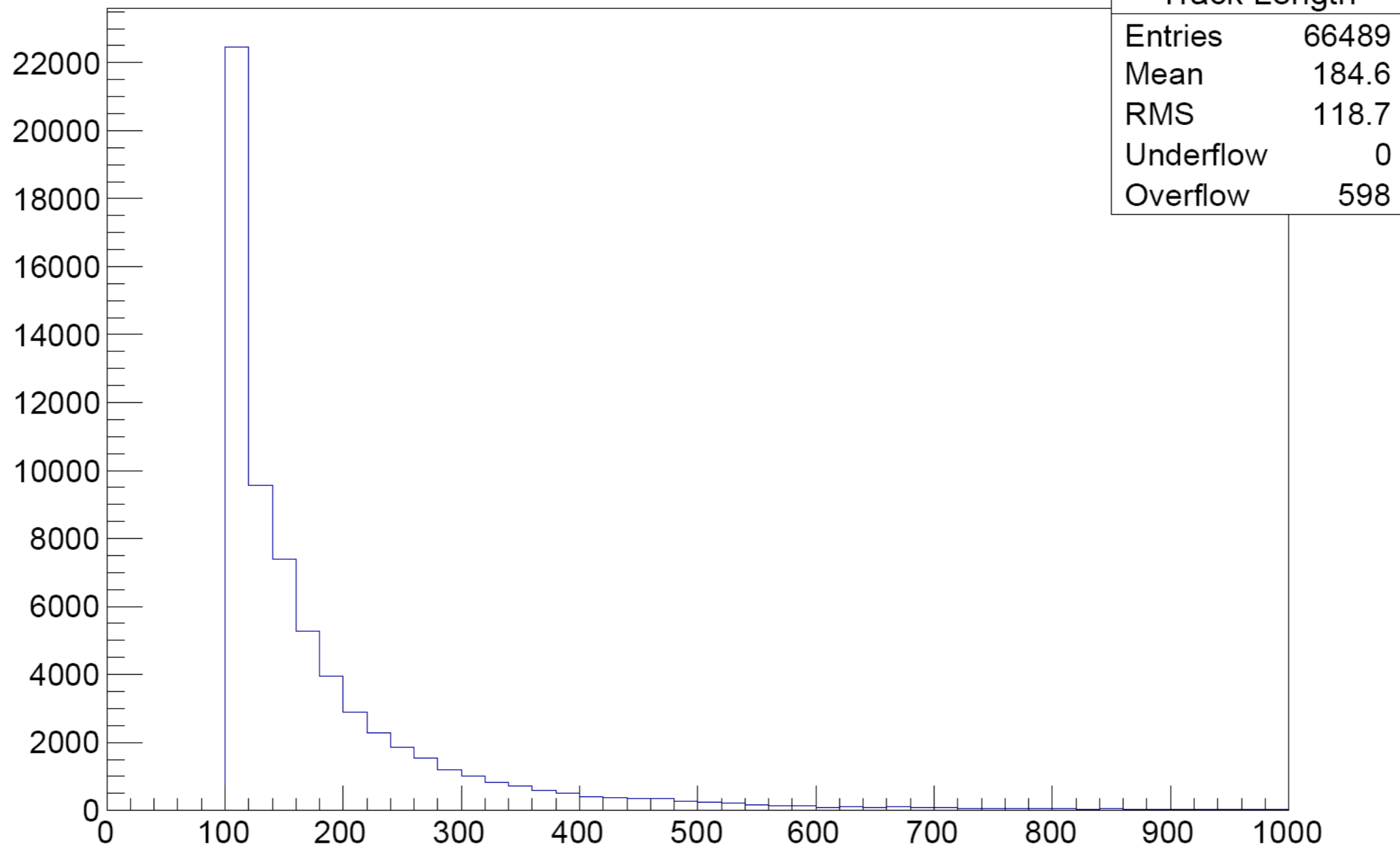
   ‣ Histogram

‣ Produces a Landau distribution

   ‣ Fit peak to extract gain…

Track Length	
Entries	66489
Mean	184.6
RMS	118.7
Underflow	0
Overflow	598
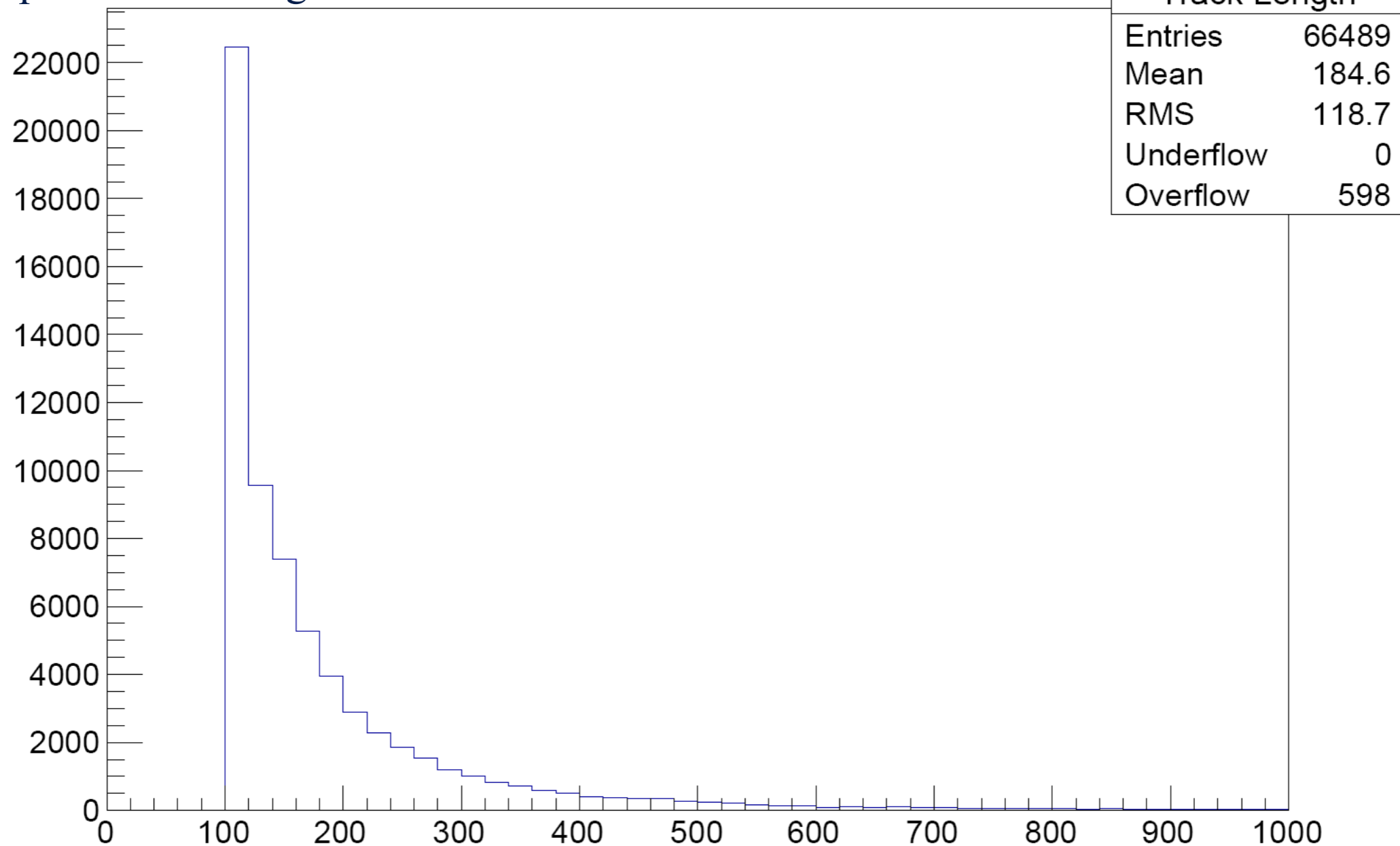
Landau Distribution

‣ ## Landau Distribution

$$f(x, \Delta) = \phi(\lambda)/\xi$$

$$\phi(\lambda) = \frac{1}{\pi} \int_0^\infty e^{-u \ln u - u\lambda} \sin(\pi u)\, du$$

$$\lambda = \frac{1}{\xi}[\Delta - \xi(\ln \xi - \ln \epsilon + 1 - C)]$$

$$\ln \epsilon = \ln \frac{(1 - \beta^2)I^2}{2mc^2\beta^2} + \beta^2$$

$K = 2\pi N_0 r_e^2 m_e c^2 = 0.1535 \text{MeV} c^2/\text{g};$

x is the path length in g/cm^2;

$r_e = \frac{e^2}{4\pi \epsilon_0 m_e c^2} = 2.8179 \times 10^{-13}$ cm is the classical electron radius;

m_e is the mass of the electron;

N_0 is Avagadro's number, 6.022×10^{23};

I is the mean excitation energy averaged over all electrons in eV;

Z is the atomic number of the medium;

A is the atomic weight of the medium;

ρ is the density of the medium;

z is the charge of the incoming particle;

$\beta = v/c$ is the ratio of the incoming particle to the speed of light;

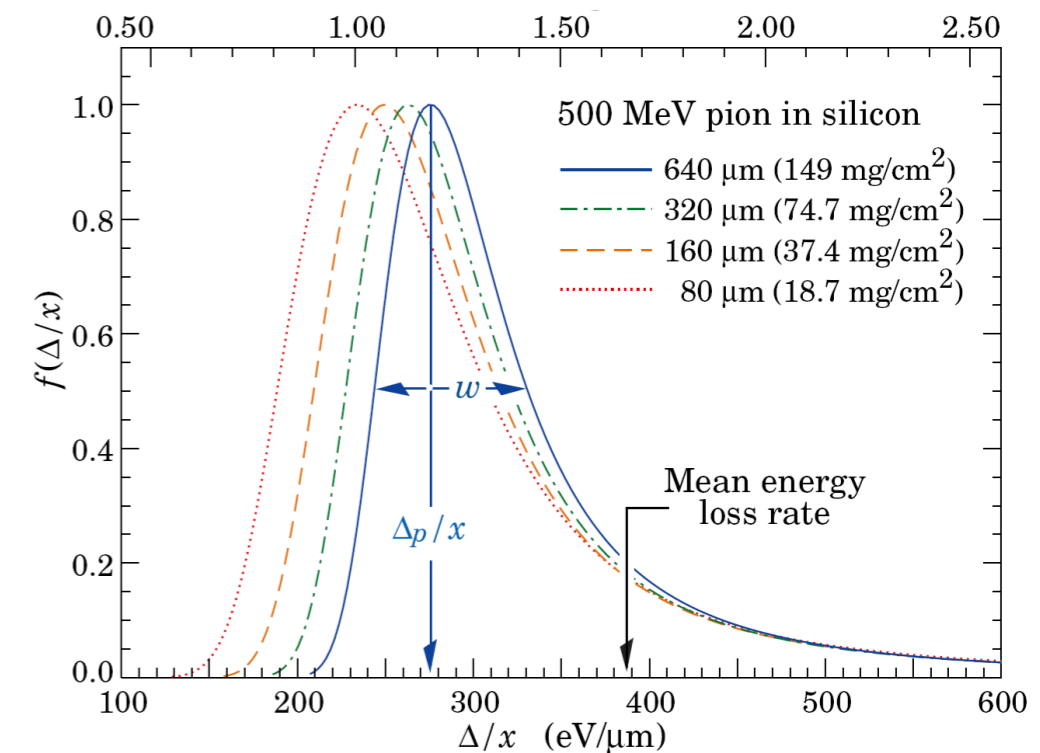γ is the Lorentz factor $\frac{1}{\sqrt{1-\beta^2}}$;

δ_{ion} is a density correction;
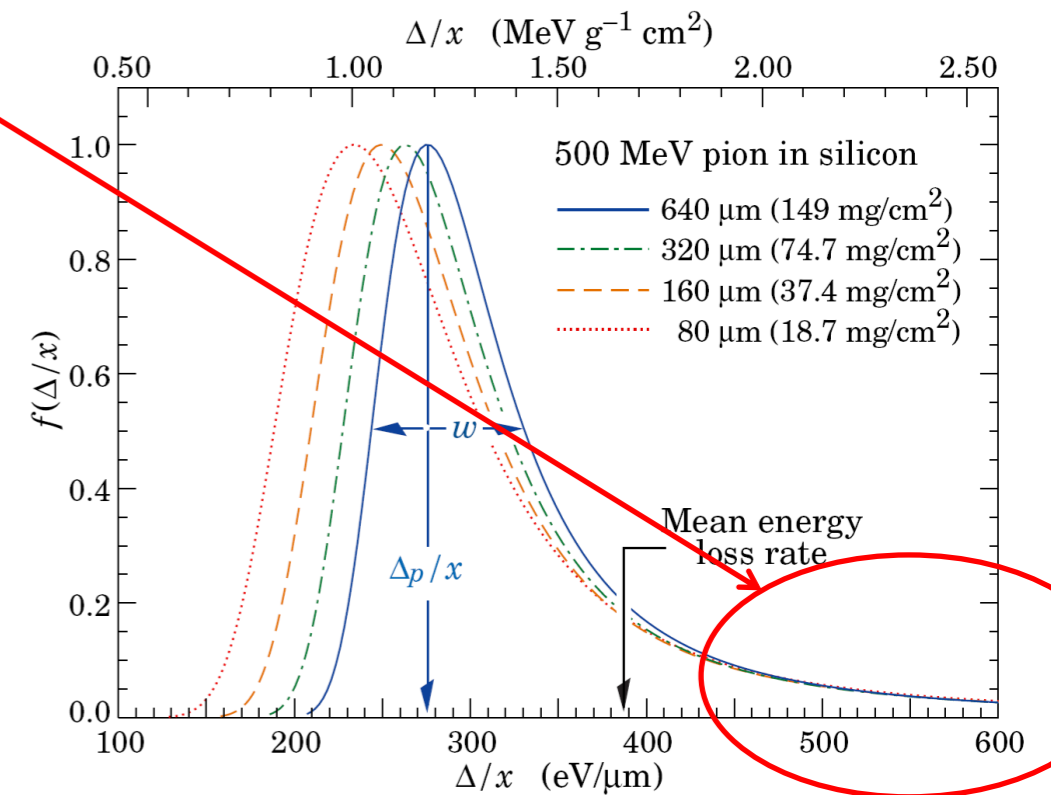
C is a shell correction;

‣ ## Peak Energy loss

$$\Delta_p = \xi \left[\ln \frac{2mc^2\beta^2\gamma^2}{I} + \ln \frac{\xi}{I} + j - \beta^2 - \delta_{ion}(\beta\gamma) \right]$$

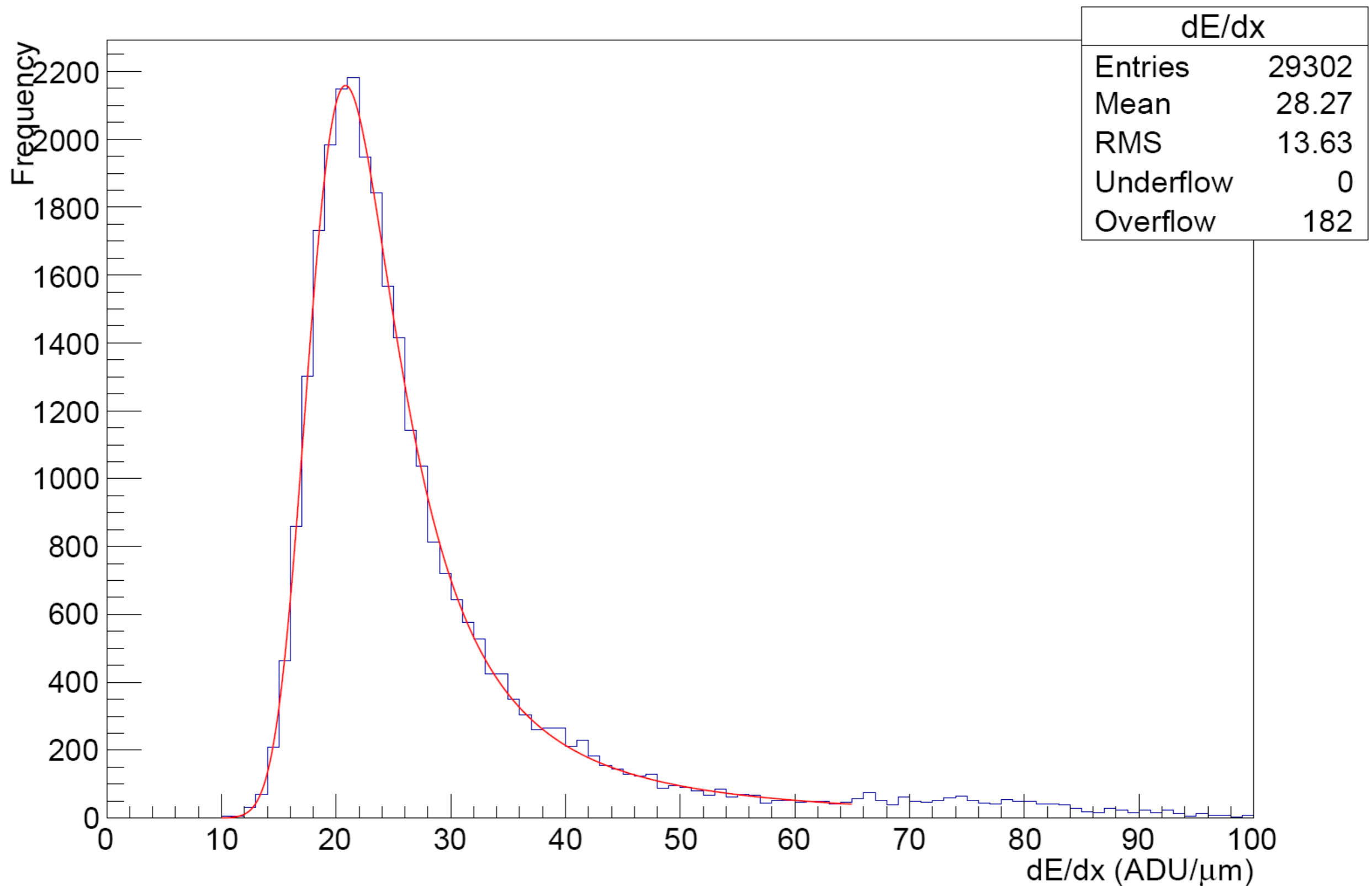$$\xi = x \cdot \frac{K}{2} \frac{Z}{A} \frac{1}{\beta^2} \text{ MeV}$$

500 MeV pion in silicon

— 640 μm (149 mg/cm^2)
—·— 320 μm (74.7 mg/cm^2)
- - - 160 μm (37.4 mg/cm^2)
···· 80 μm (18.7 mg/cm^2)

w

Δ_p/x

Mean energy loss rate

$f(\Delta/x)$

Δ/x (eV/μm)

Landau Distribution

‣ Tail goes to "infinity"

   ‣ (i.e. the energy of muon – several GeV!)

‣ This produces large δ-rays

Measured cosmic ray distribution

dE/dx	
Entries	29302
Mean	28.27
RMS	13.63
Underflow	0
Overflow	182

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Muon energy spectrum - Amp 1

MPV = 18.81 ± 0.12 ADU

Entries = 1910.0

χ^2_{red} = 1.87

Plot peaks against each other for each amplifier

^{55}Fe Spectrum - Amp 1

K_α peak = 479.19 ± 0.05 ADU

Entries = 38359

χ^2_{red} = 5.16

R^2 = 0.801
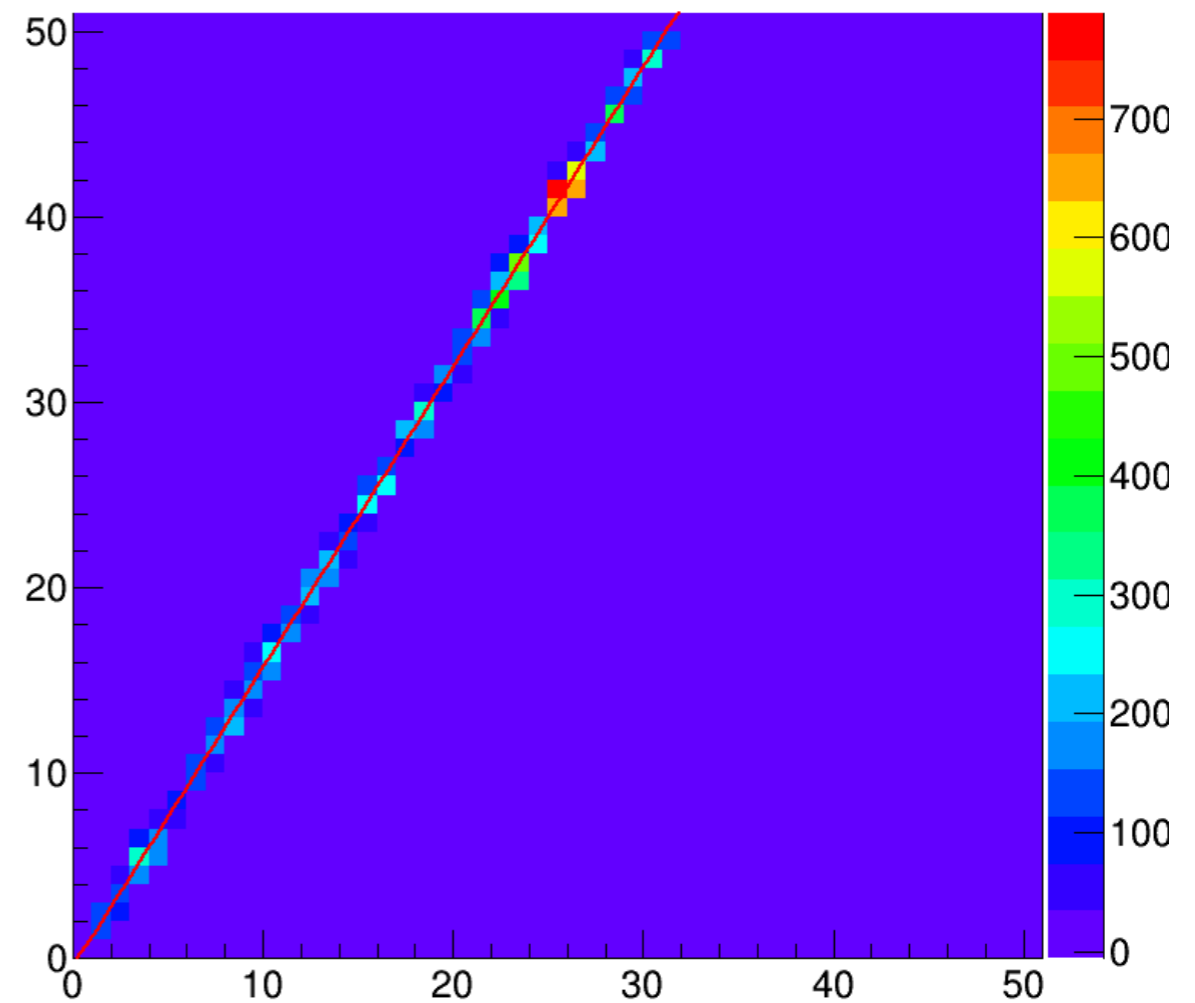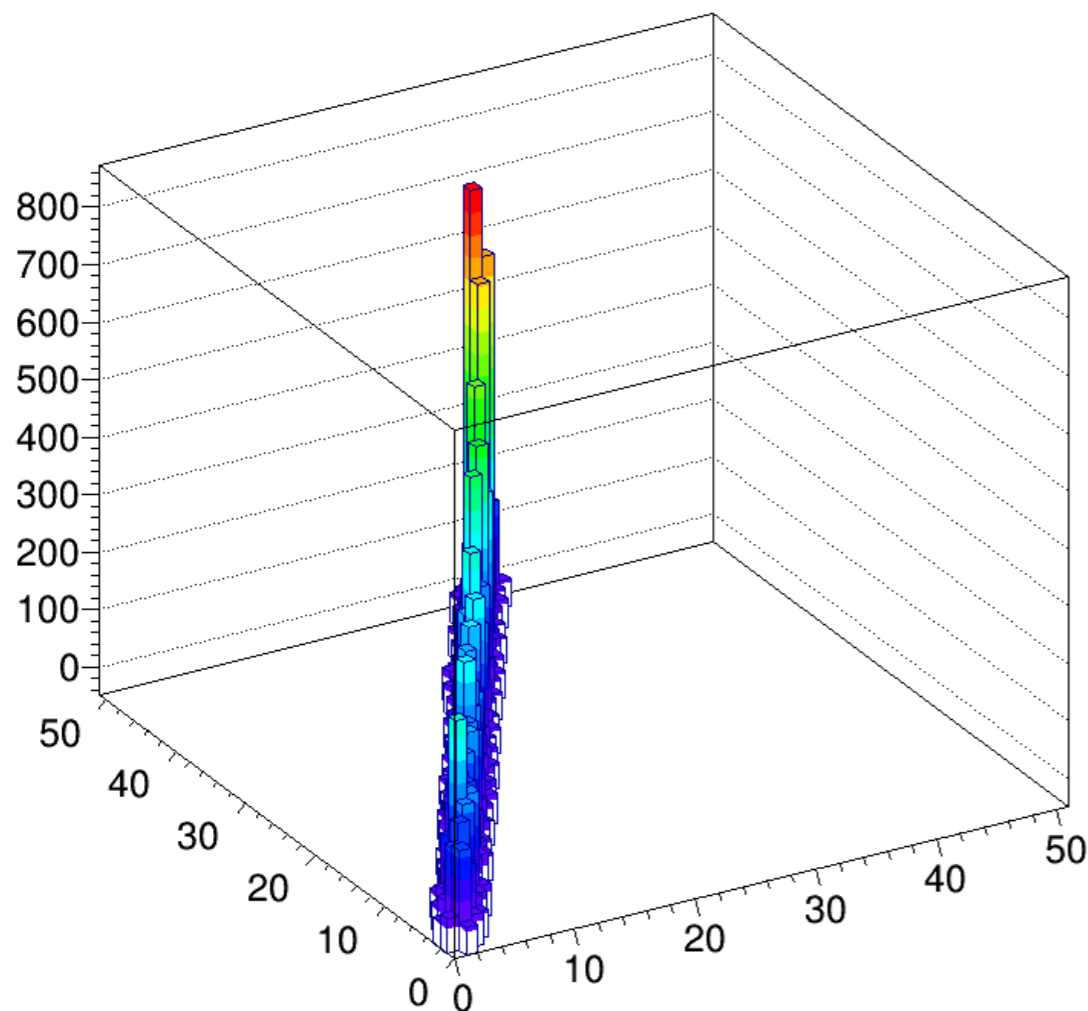
χ^2_{red} = 1.1
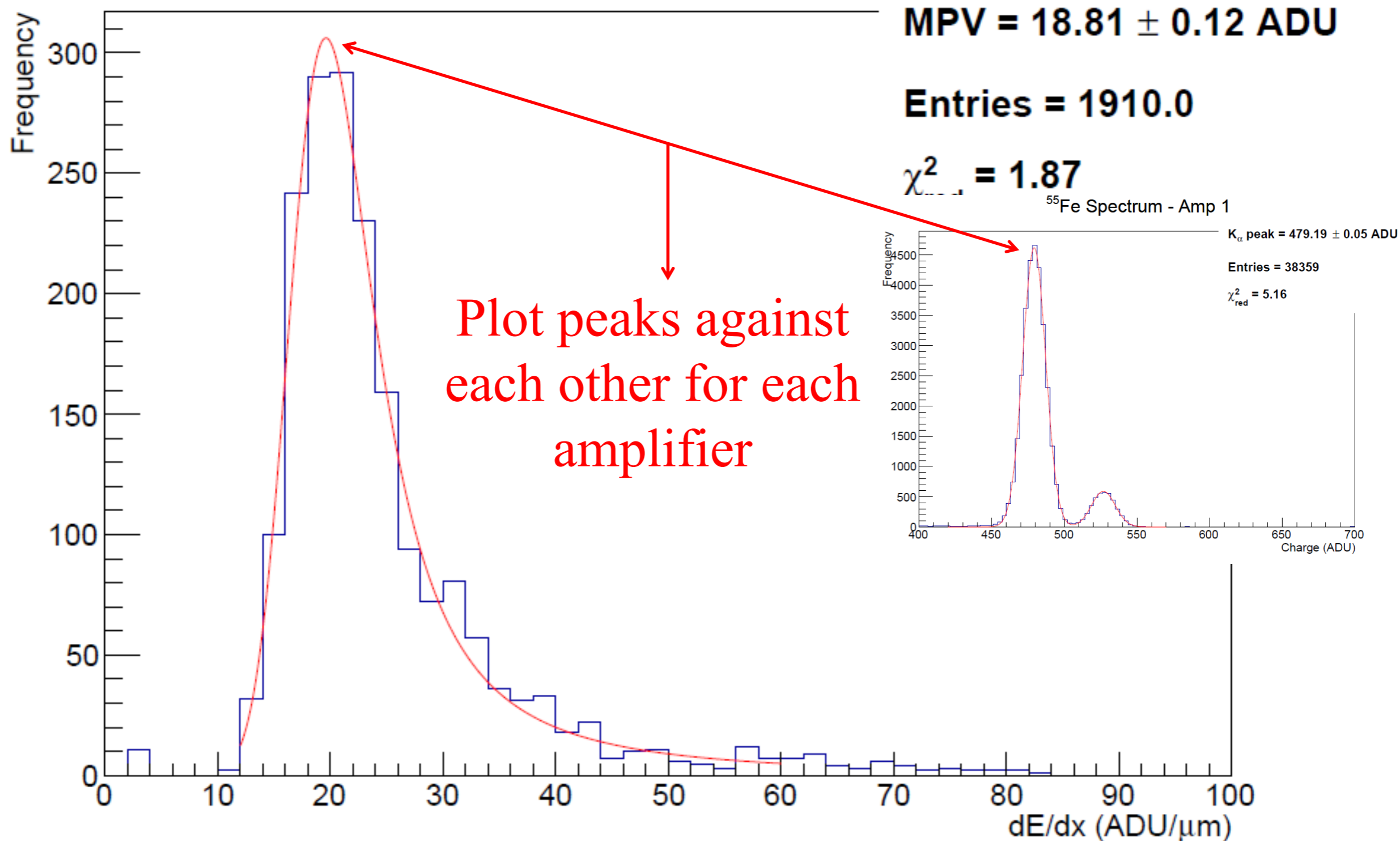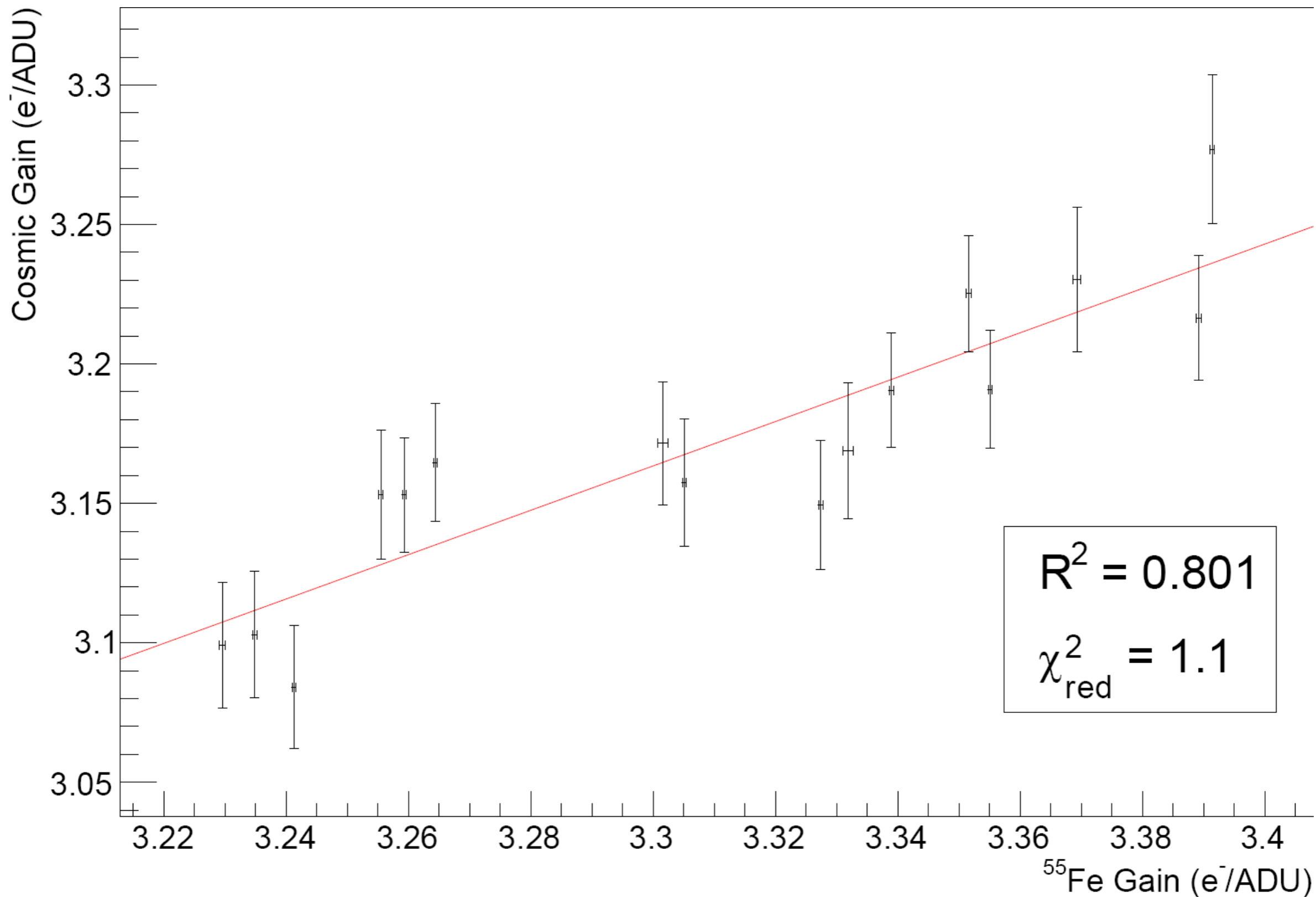
‣ Conclusion:

   ‣ You can measure gain without using ^{55}Fe or PTC

   ‣ You will get this information "for free" on the sky
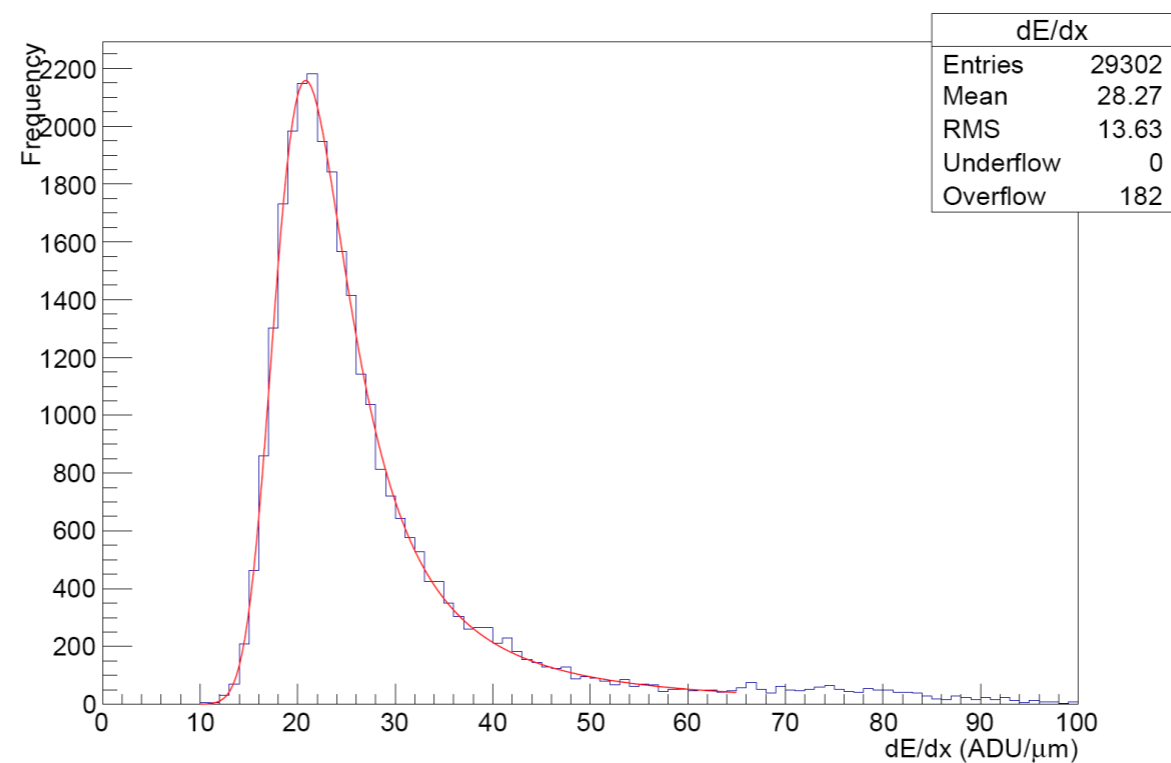
Diffusion measurement

Diffusion Measurement

‣ **Fit track with straight line**

  ‣ Plot intensity as a function of distance to the track
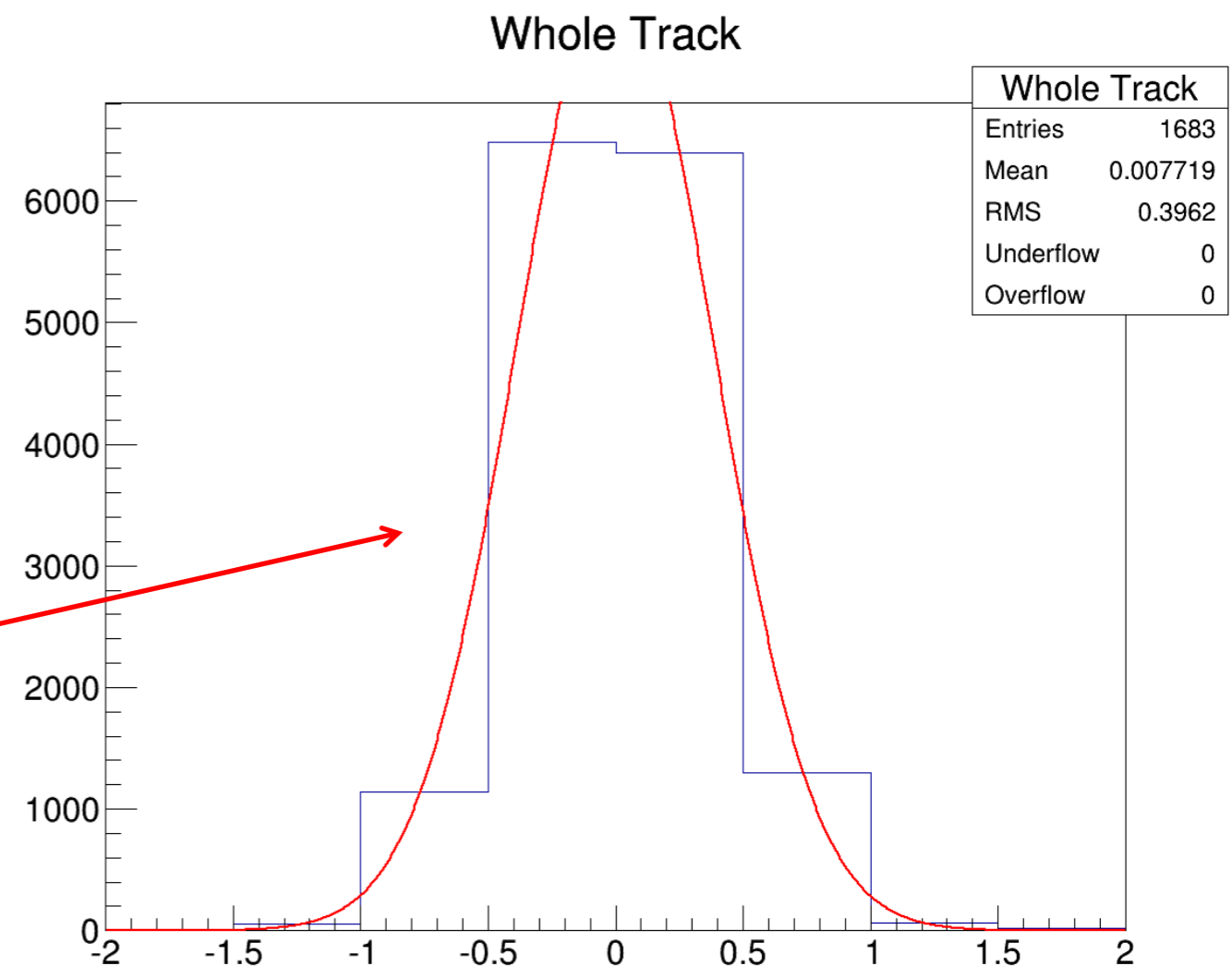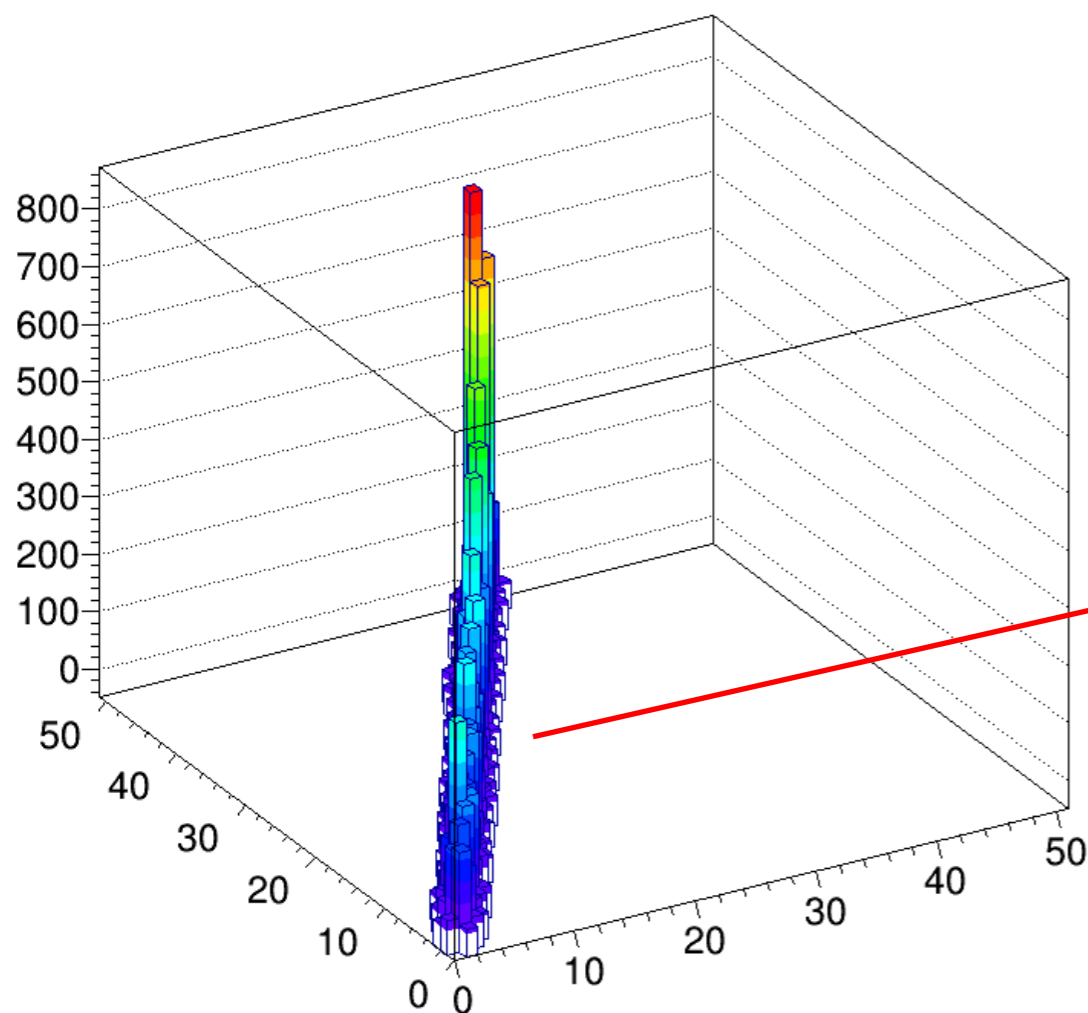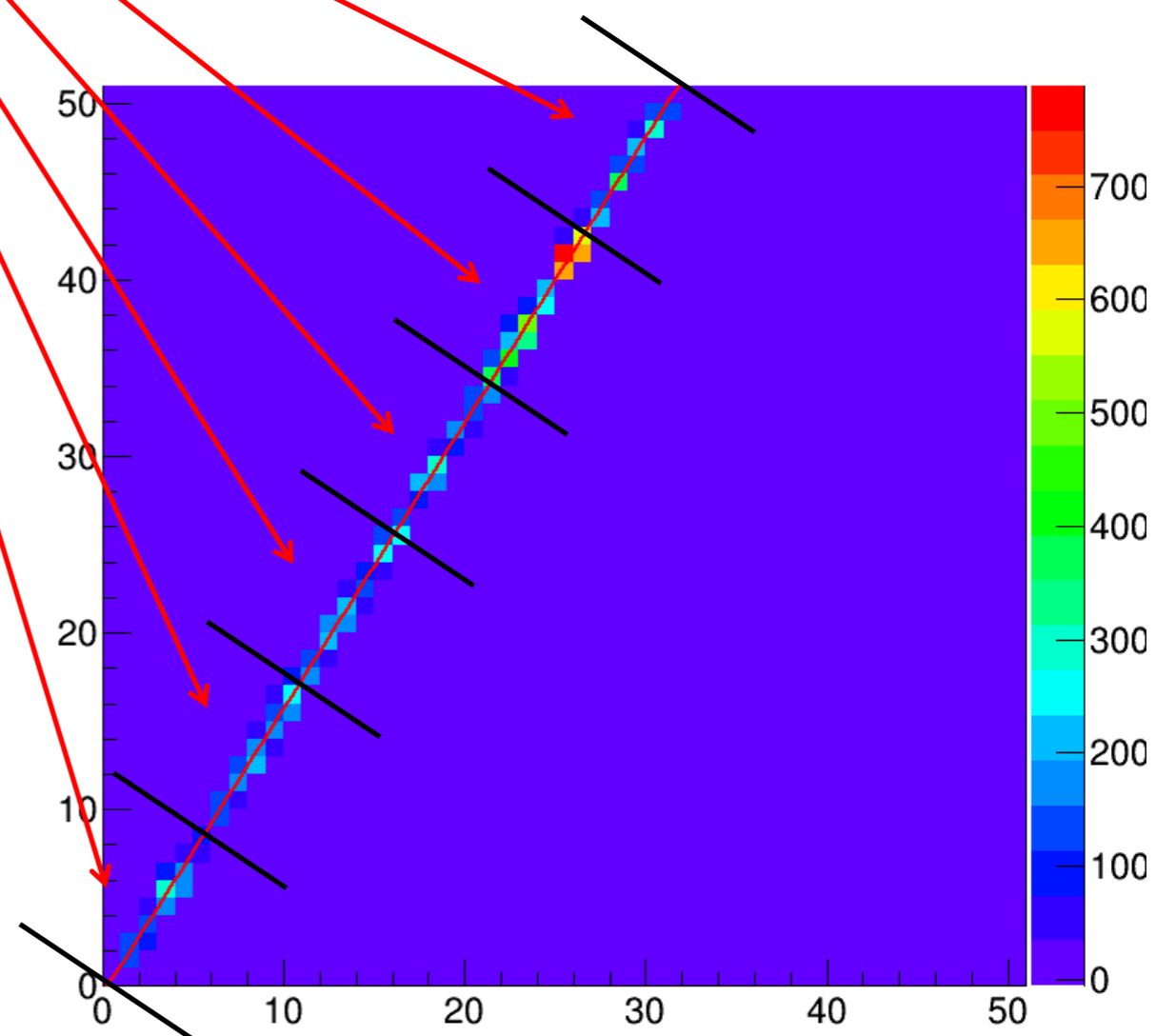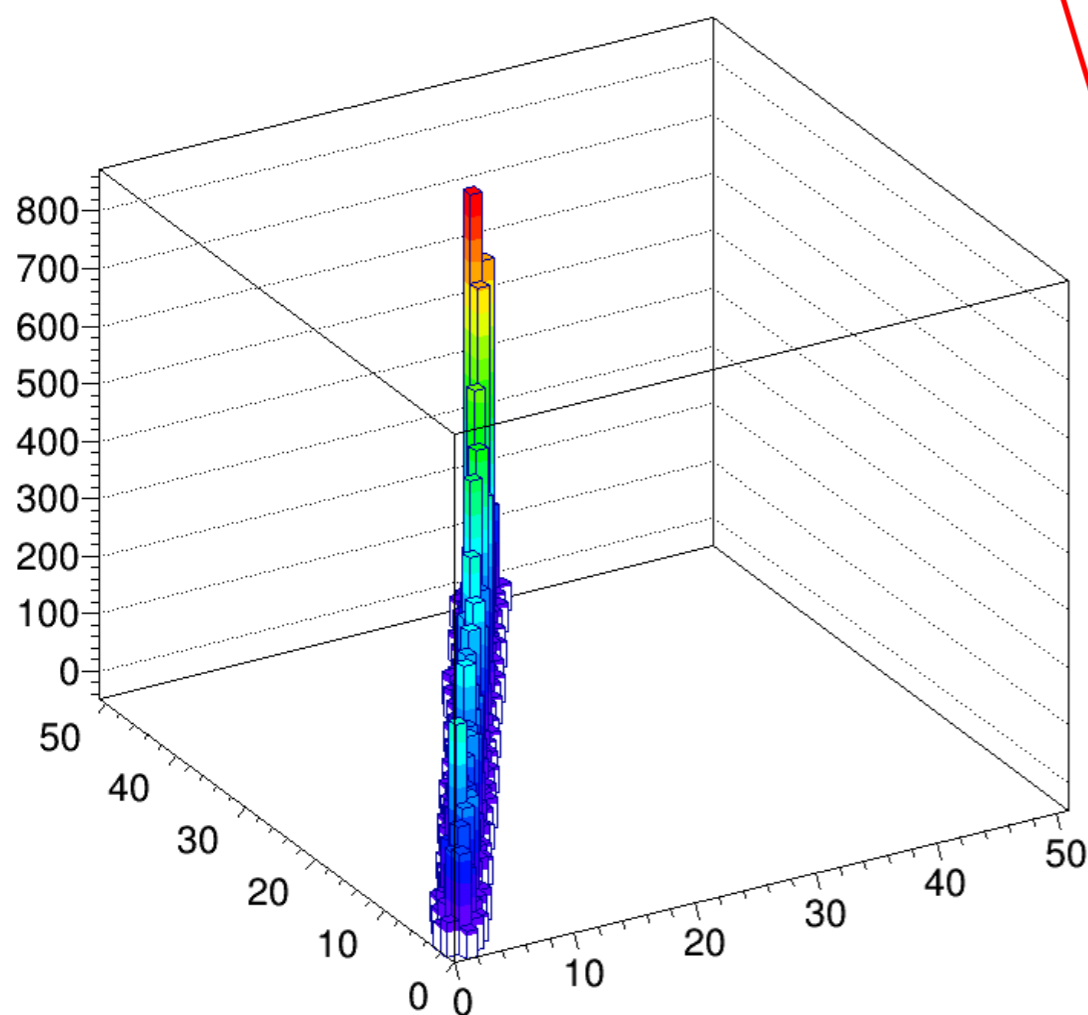 ‣ Fit a Gaussian to get the PSF

Diffusion Measurement

‣ Fit track with straight line

  ‣ Plot intensity as a function of distance to the track
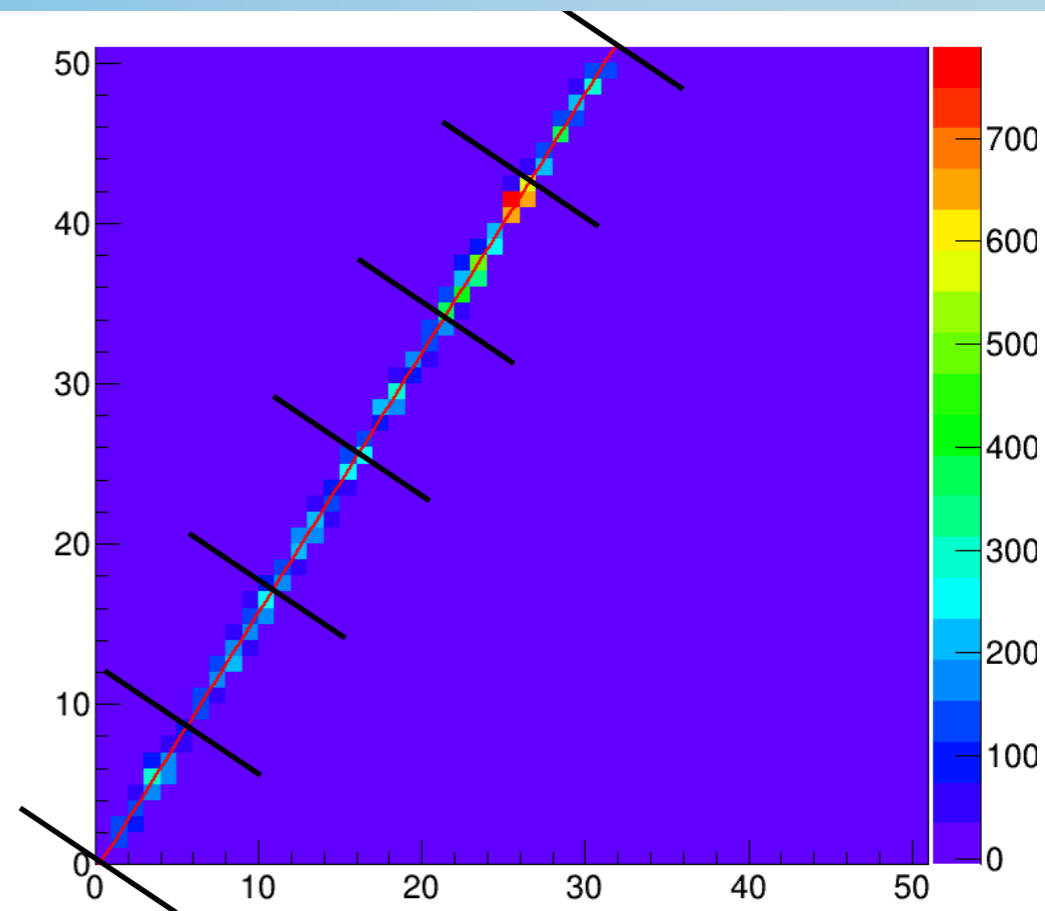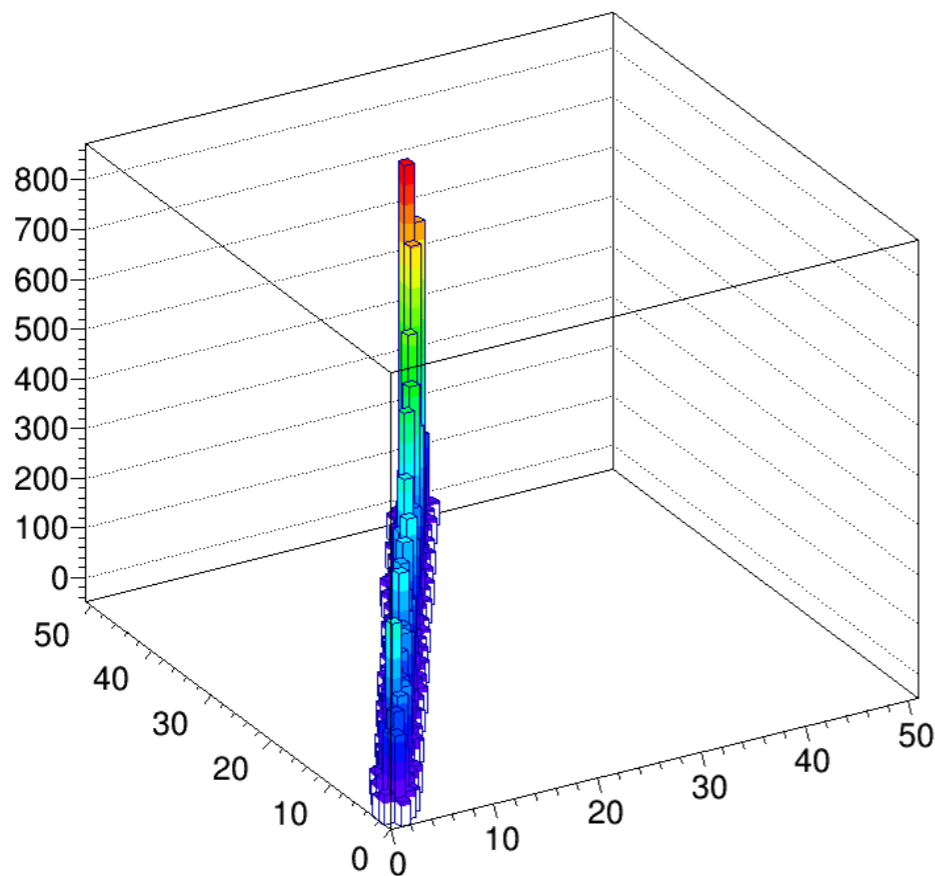 ‣ Fit a Gaussian to get the PSF

Track Segmentation

‣ To measure diffusion as a function of depth:

    ‣ Divide track into n segments

Track Segmentation

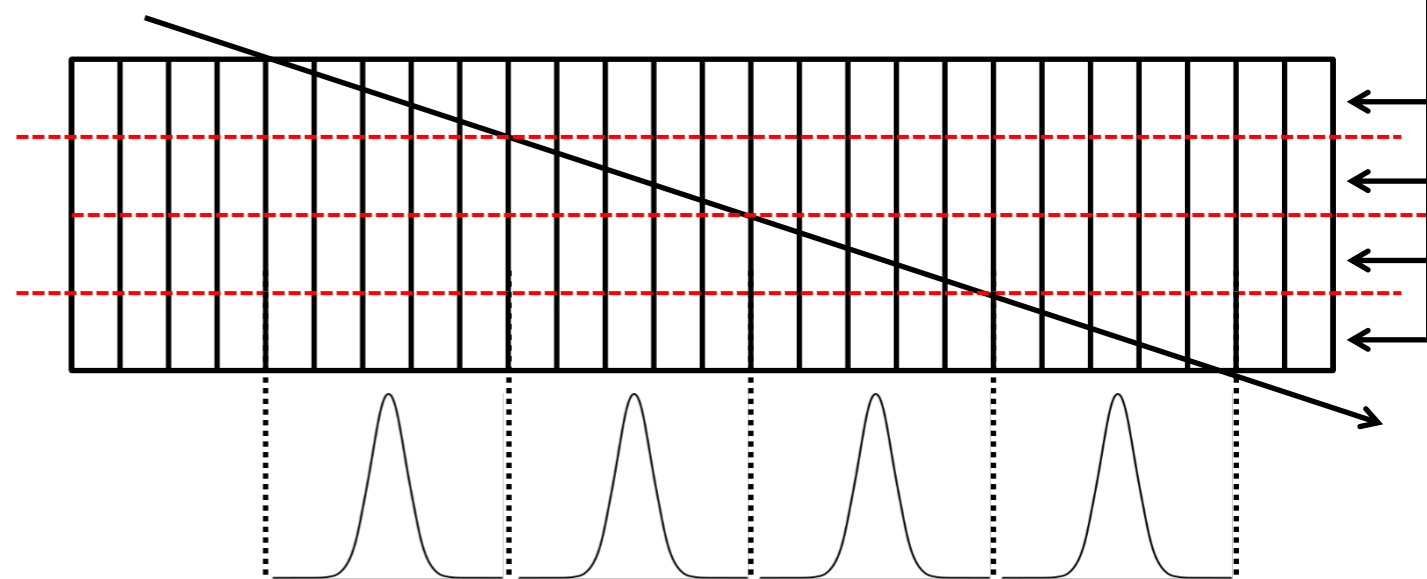- Take a long track
  - Divide track into n segments
  - For each segment:
    - Produce histogram of intensity as a function of distance to the track
    - Fit a Gaussian to get the PSF
  - Plot the widths of these Gaussians w.r.t. track segment number (i.e. depth)
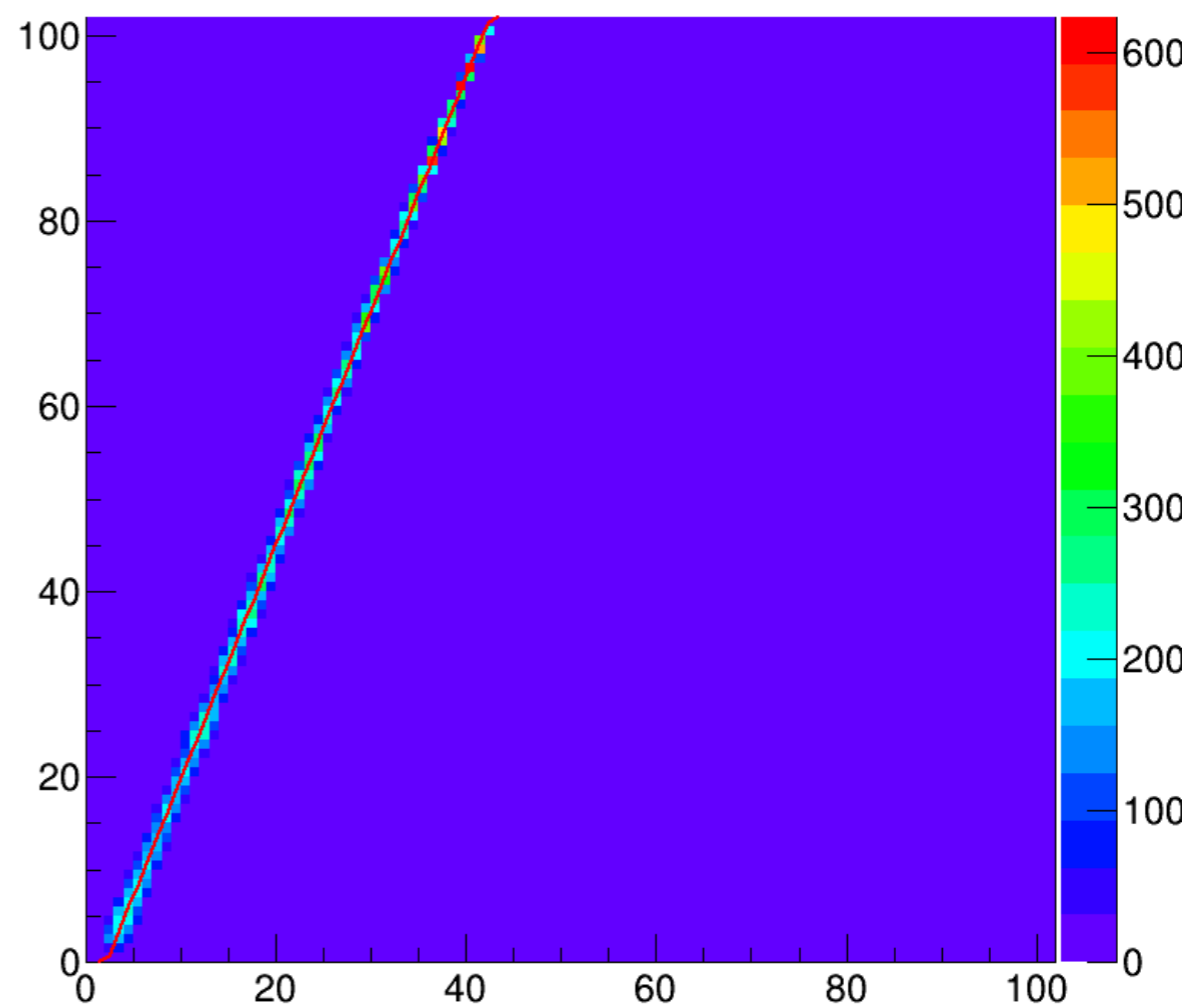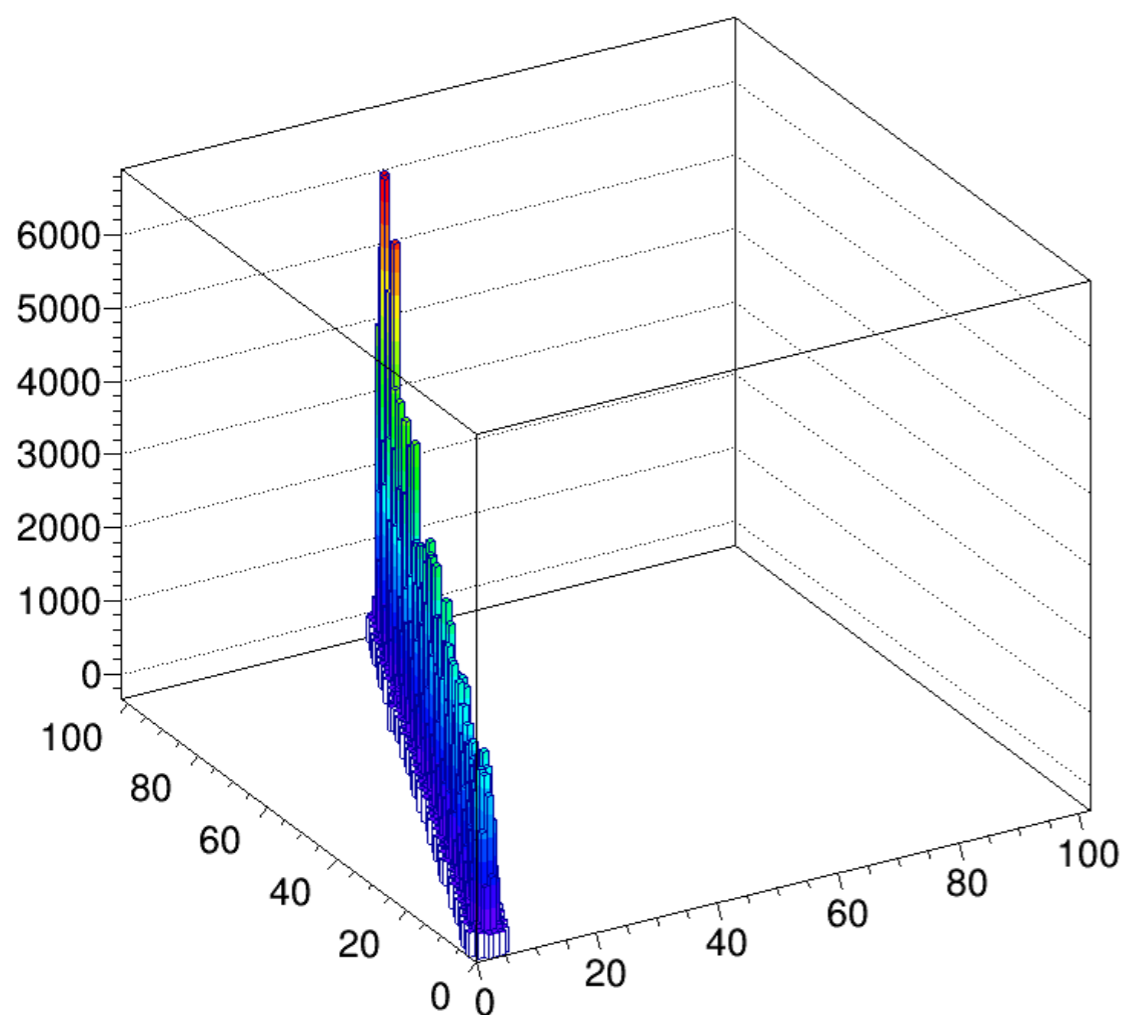
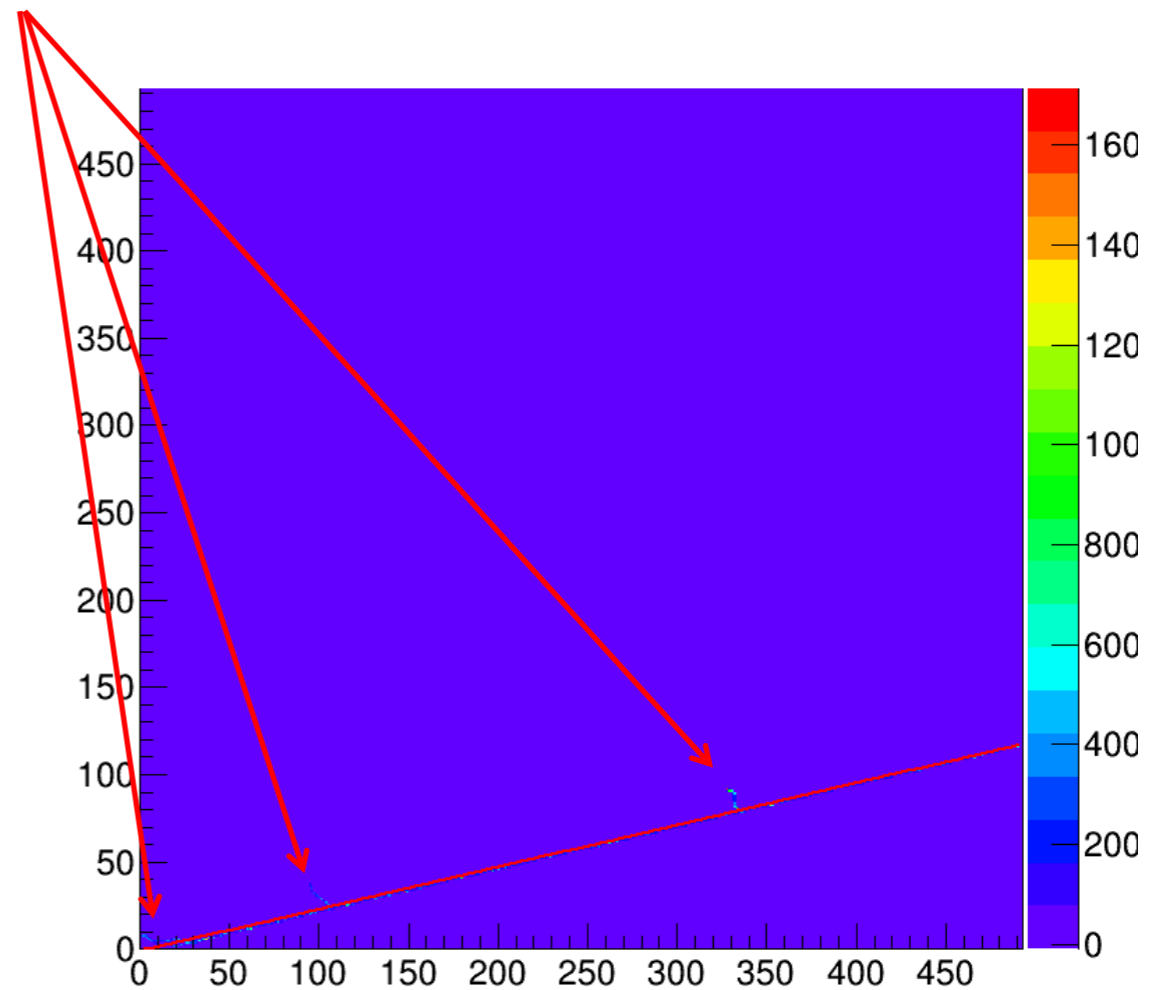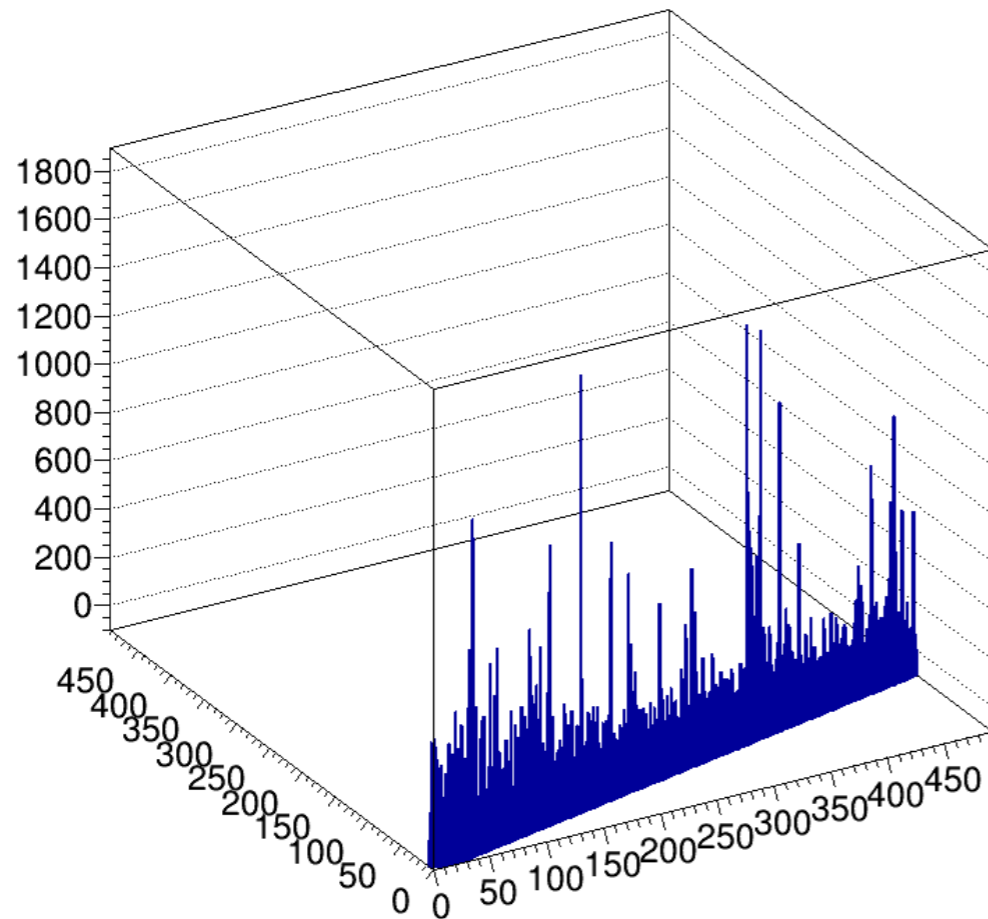Long muon track   average collection depths

‣ Nice example of a track changing in PSF with depth in sensor

Track cleaning

‣ However, unlike for gain measurement, when measuring diffusion δ-rays must be ***excluded***

  ‣ They will ruin the PSF measurement for the depth at which they occur

Remove tracks with deltas

Track cleaning

‣ Unlike for gain measurement, when measuring diffusion, δ-rays must be *excluded*

> ‣ They will ruin the PSF measurement for the depth at which they occur

Remove tracks with deltas

Track cleaning

‣ Unlike for gain measurement, when measuring diffusion, δ-rays must be *excluded*

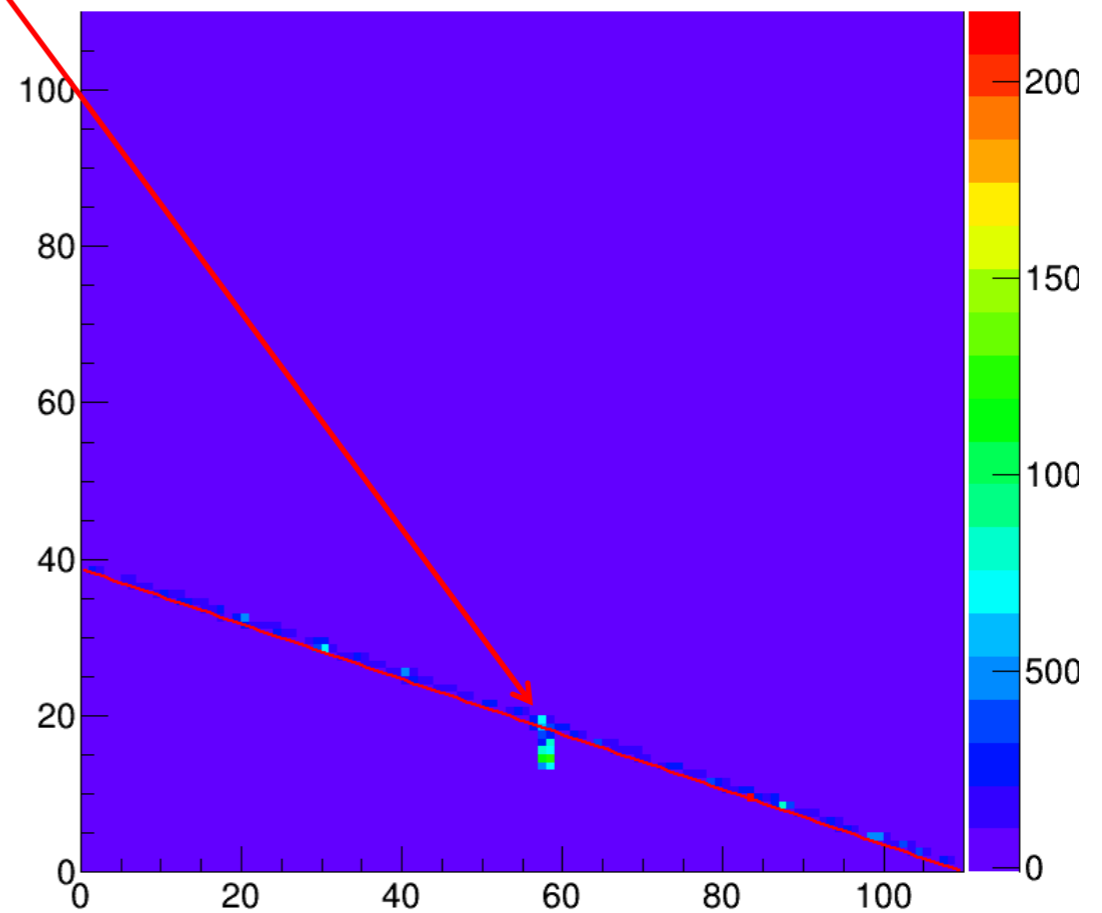 ‣ They will ruin the PSF measurement for the depth at which they occur
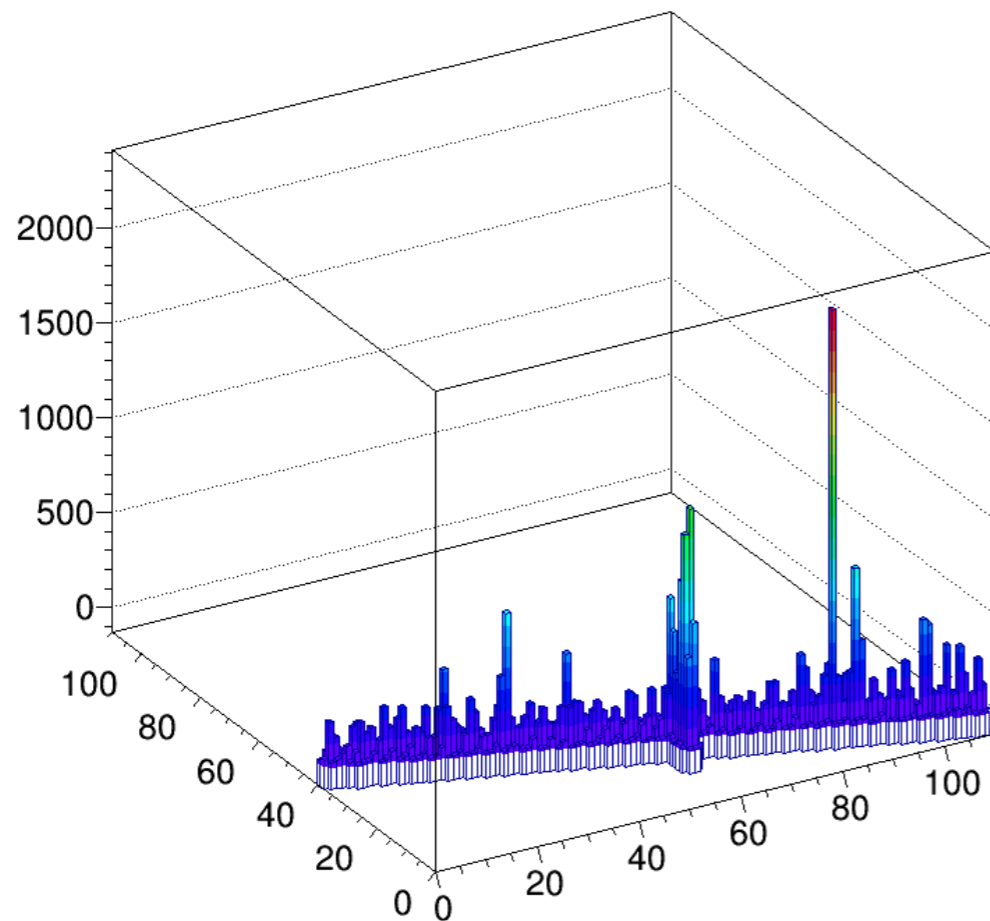
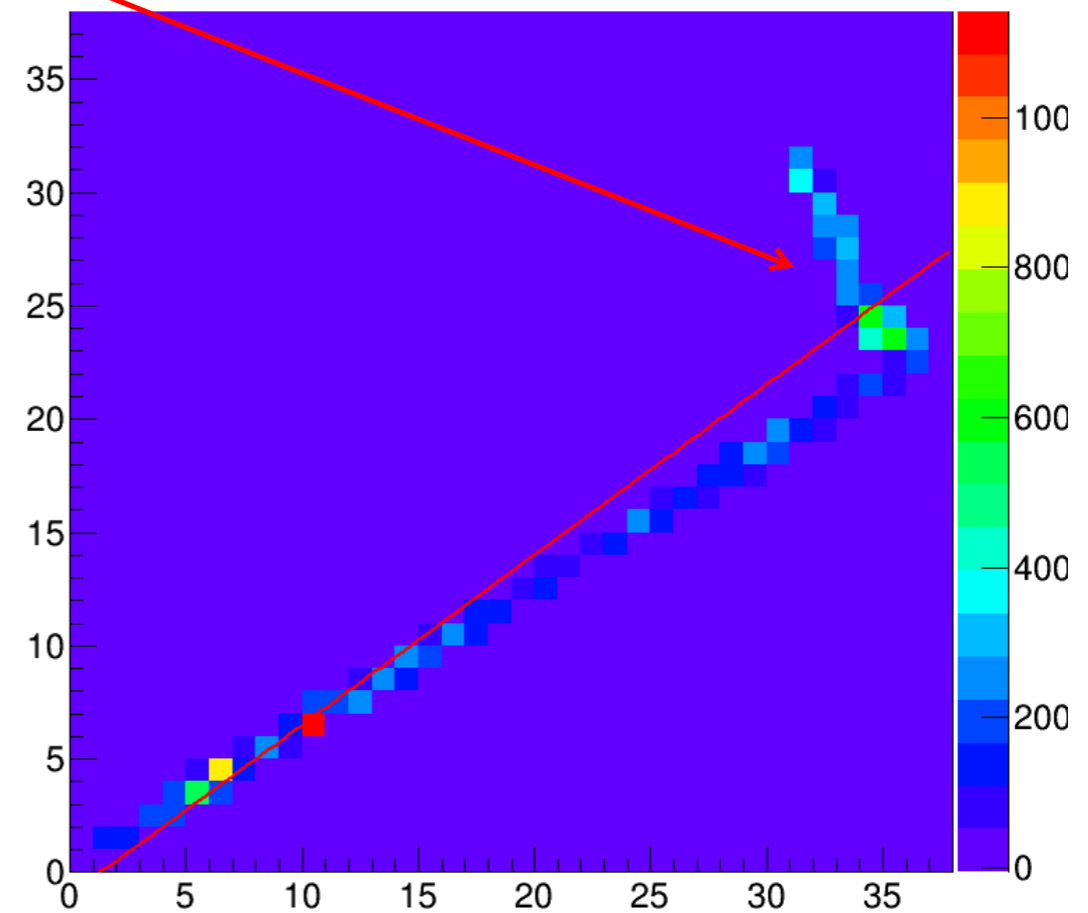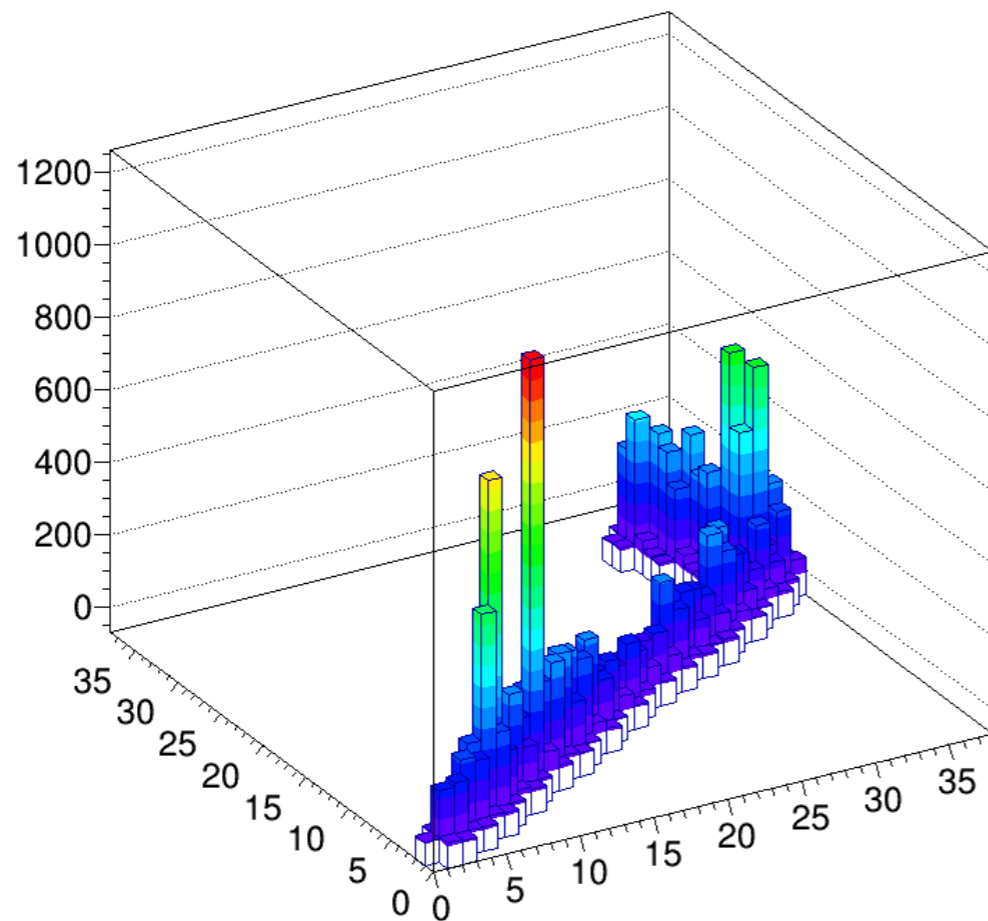## Remove tracks with deltas

Track cleaning

‣ **Find all tracks in dataset**

   ‣ Cut dataset to only include long & straight tracks

   ‣ Remove tracks with large delta–rays as these ruin PSF for a certain depth

Remove tracks with deltas
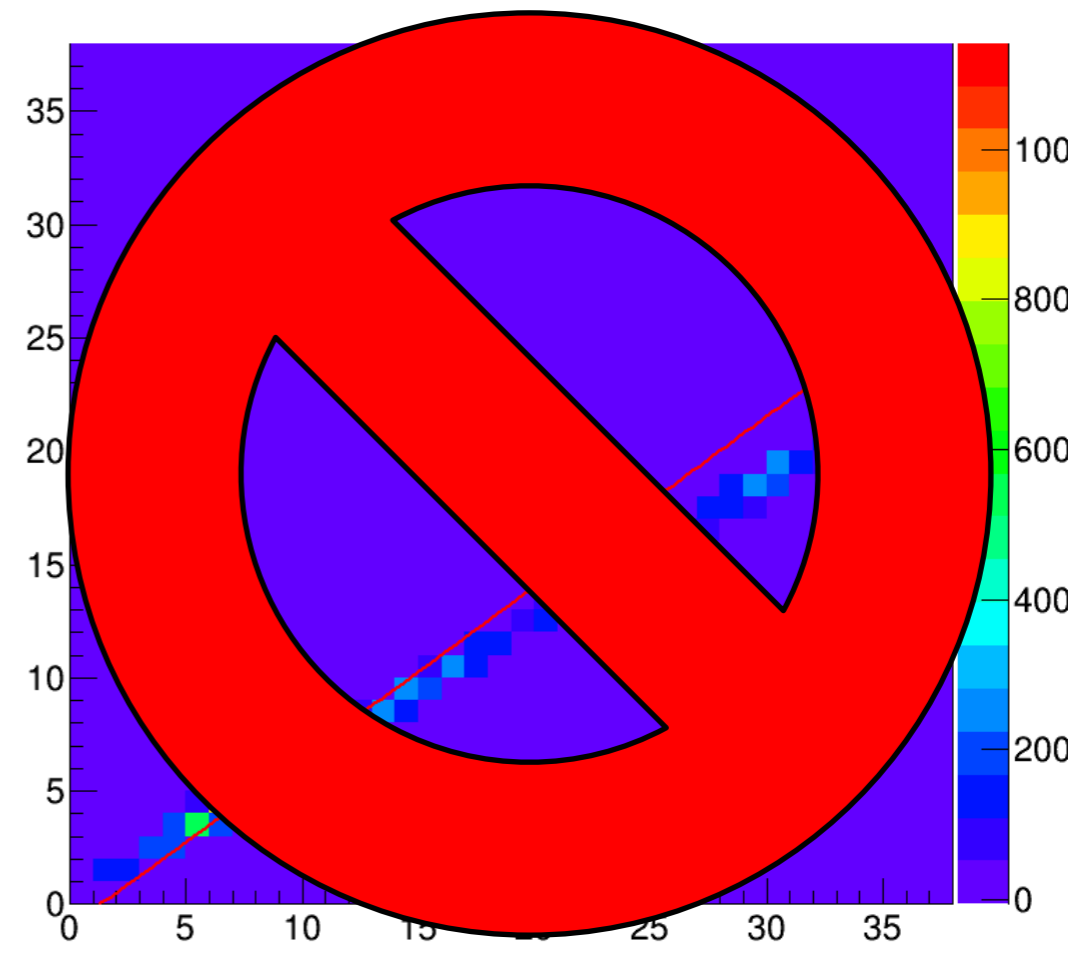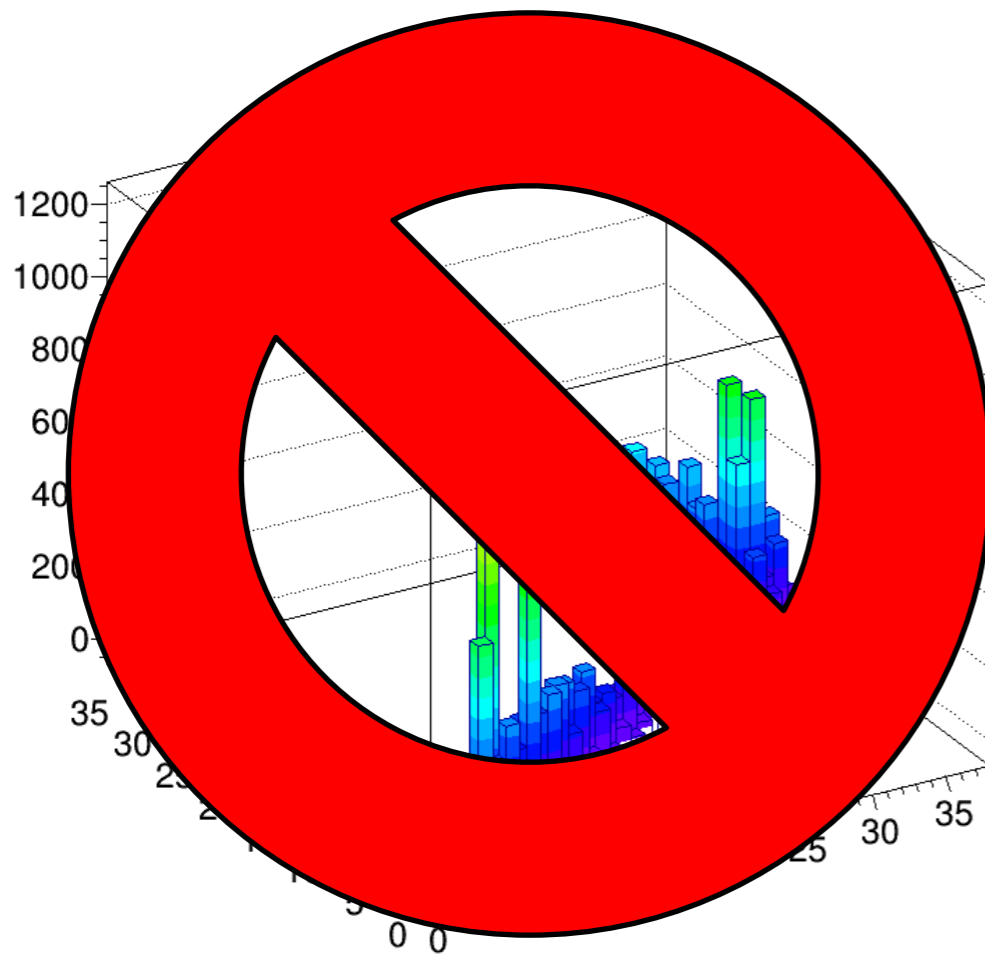
Track Segmentation

‣ **Fit each track with straight line**

    ‣ Divide track into n segments

    ‣ For each segment:

        ‣ Produce histogram of intensity as a function of distance to the track

        ‣ Fit a Gaussian to get the PSF

Segment Measurement

‣ **Fit each track with straight line**

  ‣ Divide track into n segments

  ‣ For each segment:

    ‣ Produce histogram of intensity as a function of distance to the track

    ‣ Fit a Gaussian to get the PSF

mean = 0.0 ± 0.0 μm

σ = 0.4807 ± 0.0078 μm

Track section 0

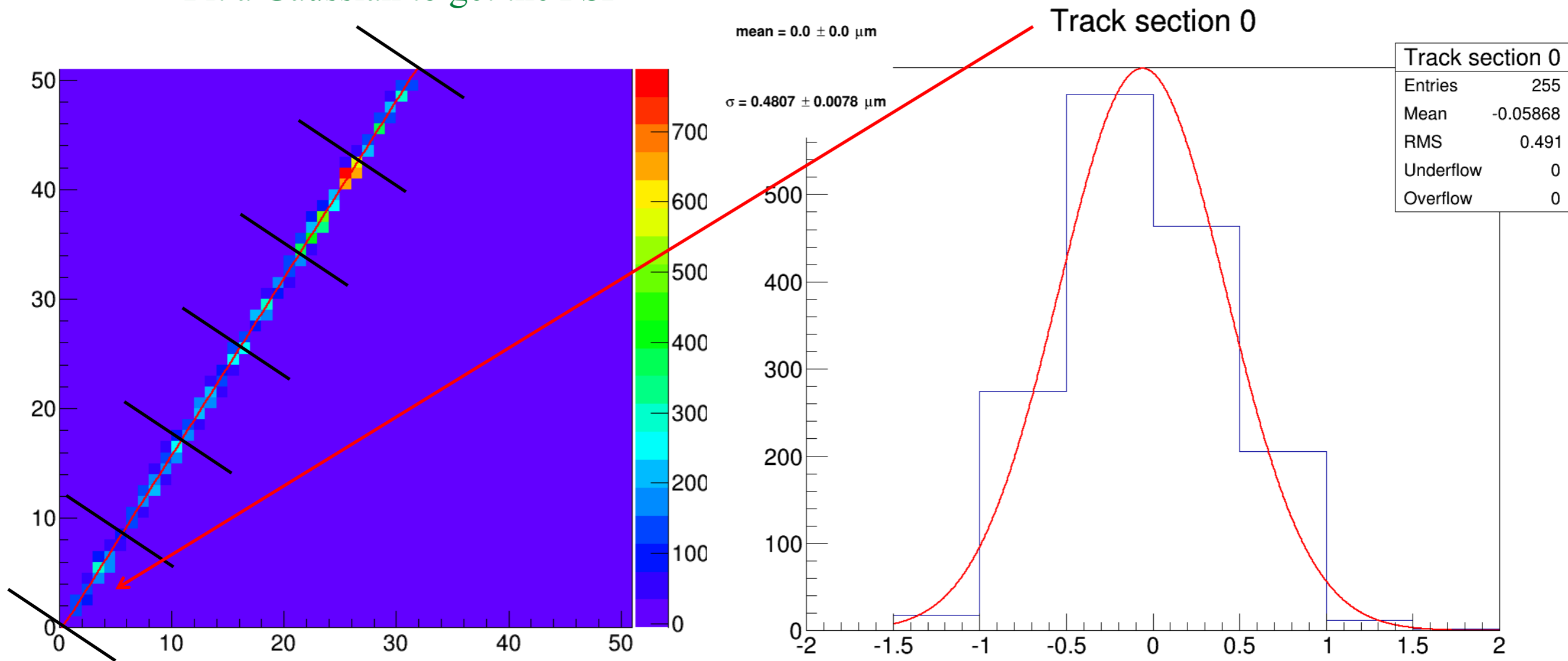| Track section 0	
Entries	255
Mean	-0.05868
RMS	0.491
Underflow	0
Overflow	0

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Segment Measurement

- **Fit each track with straight line**
  - Divide track into n segments
  - For each segment:
    - Produce histogram of intensity as a function of distance to the track
    - Fit a Gaussian to get the PSF

mean = 0.0 ± 0.0 μm

σ = 0.4065 ± 0.0072 μm

Track section 1

Track section 1	
Entries	306
Mean	0.02089
RMS	0.4317
Underflow	0
Overflow	0

Segment Measurement

‣ **Fit each track with straight line**

   ‣ Divide track into n segments

   ‣ For each segment:

      ‣ Produce histogram of intensity as a function of distance to the track

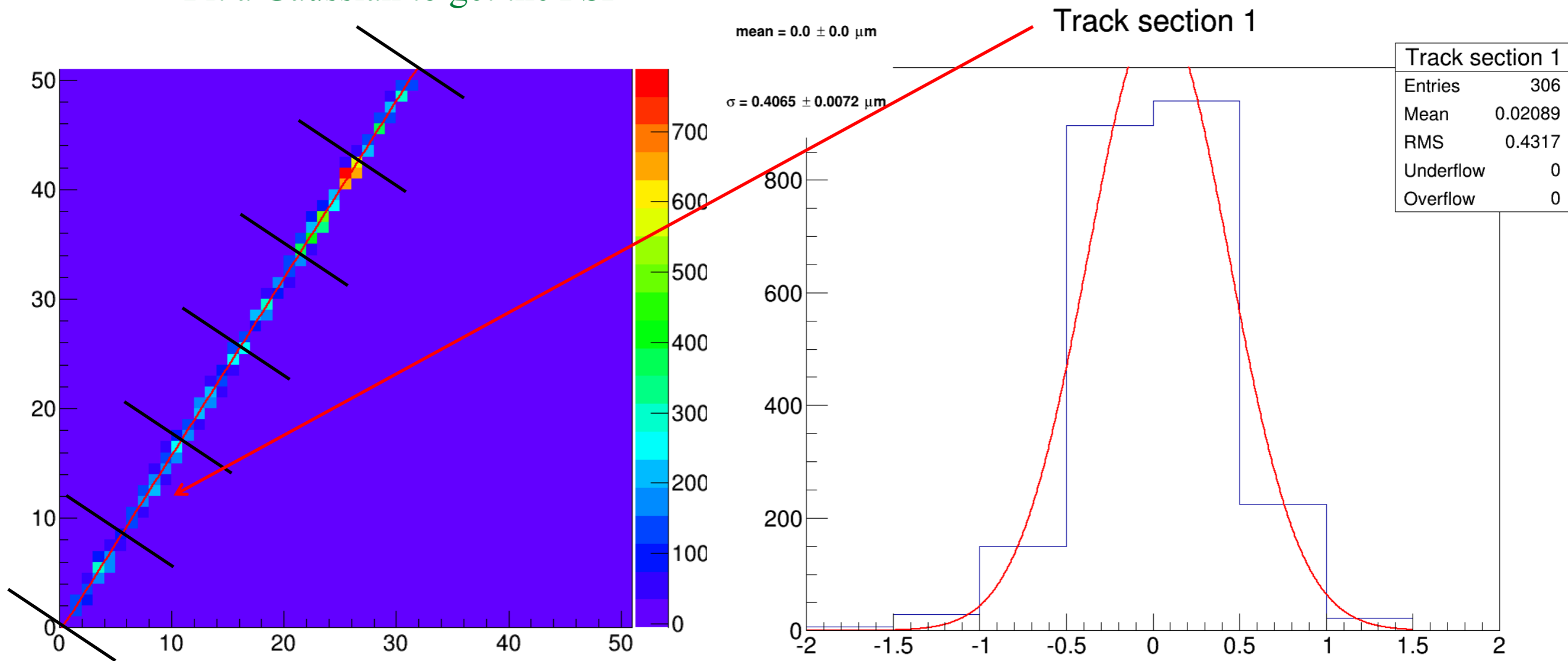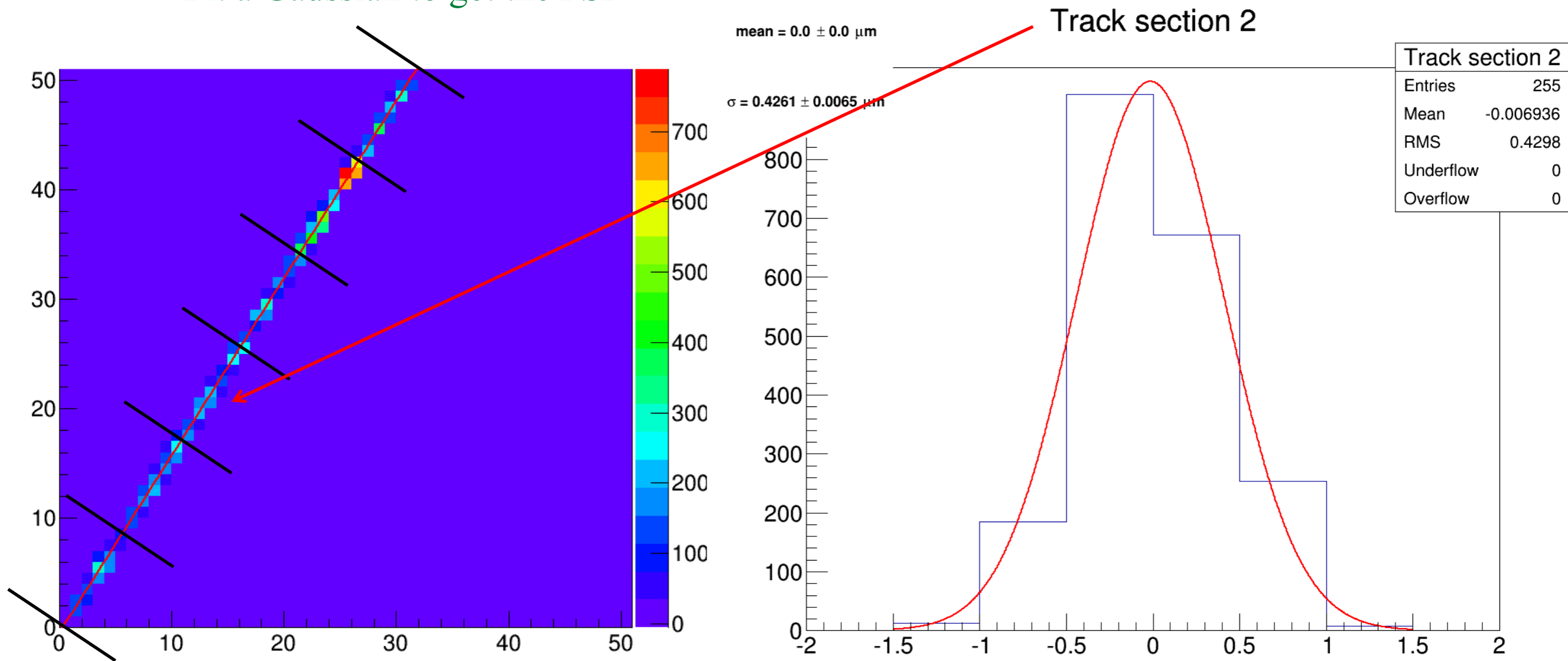   ‣ Fit a Gaussian to get the PSF

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Segment Measurement

‣ **Fit each track with straight line**

    ‣ Divide track into n segments

    ‣ For each segment:

        ‣ Produce histogram of intensity as a function of distance to the track

        ‣ Fit a Gaussian to get the PSF

mean = 0.0 ± 0.0 μm

σ = 0.3531 ± 0.0051 μm

Track section 3

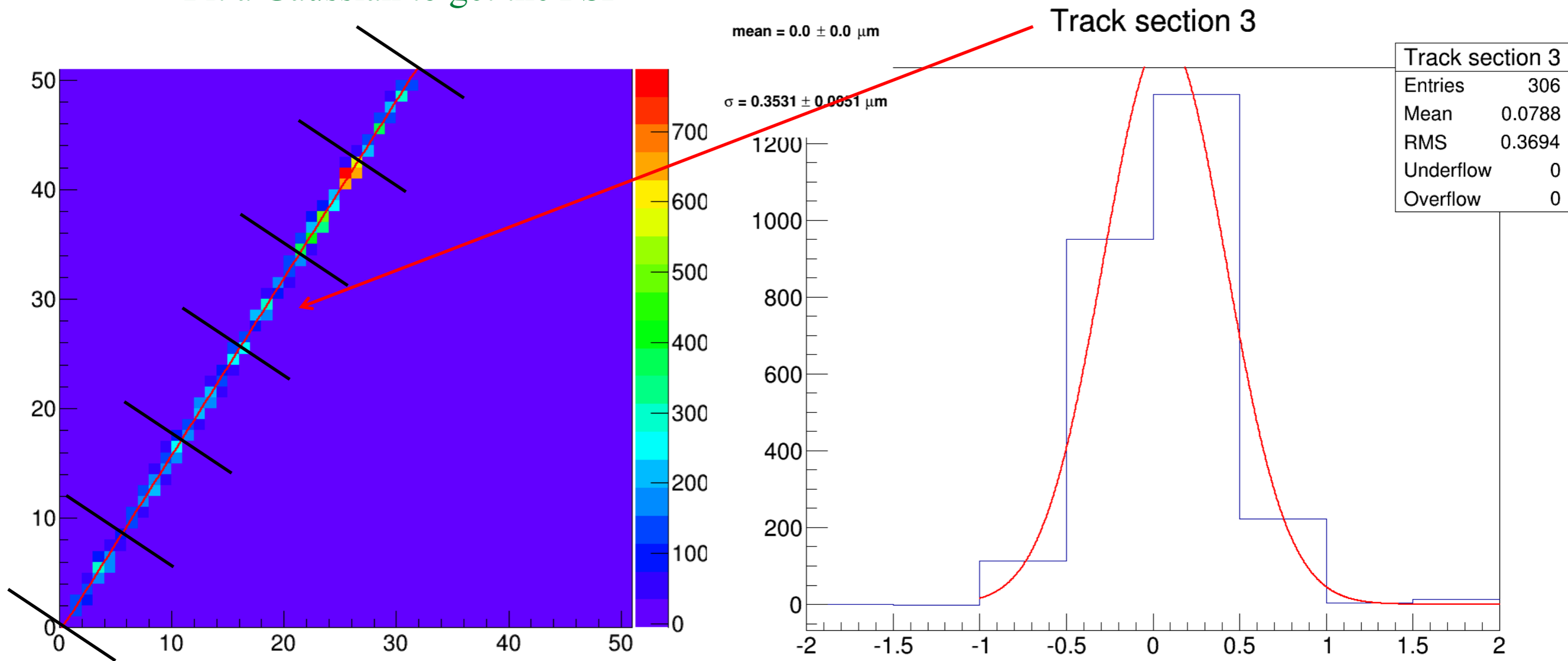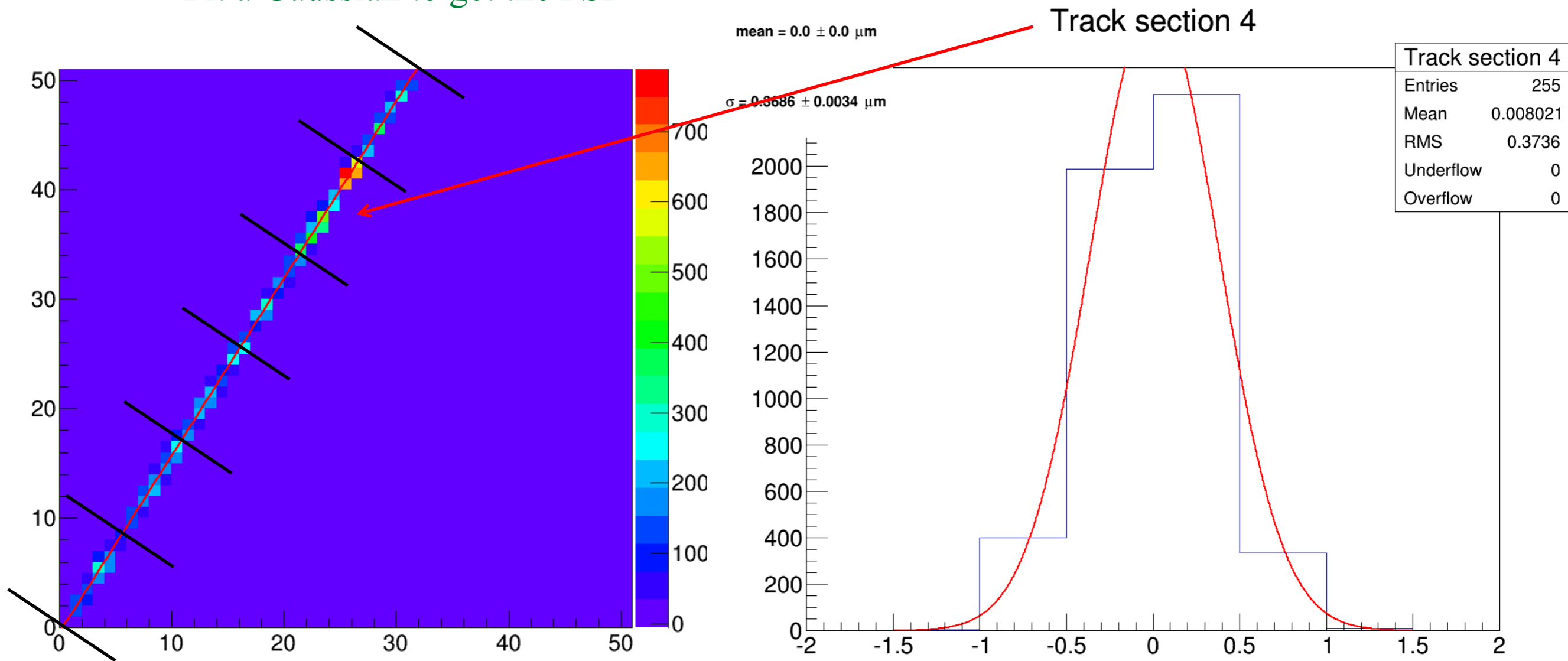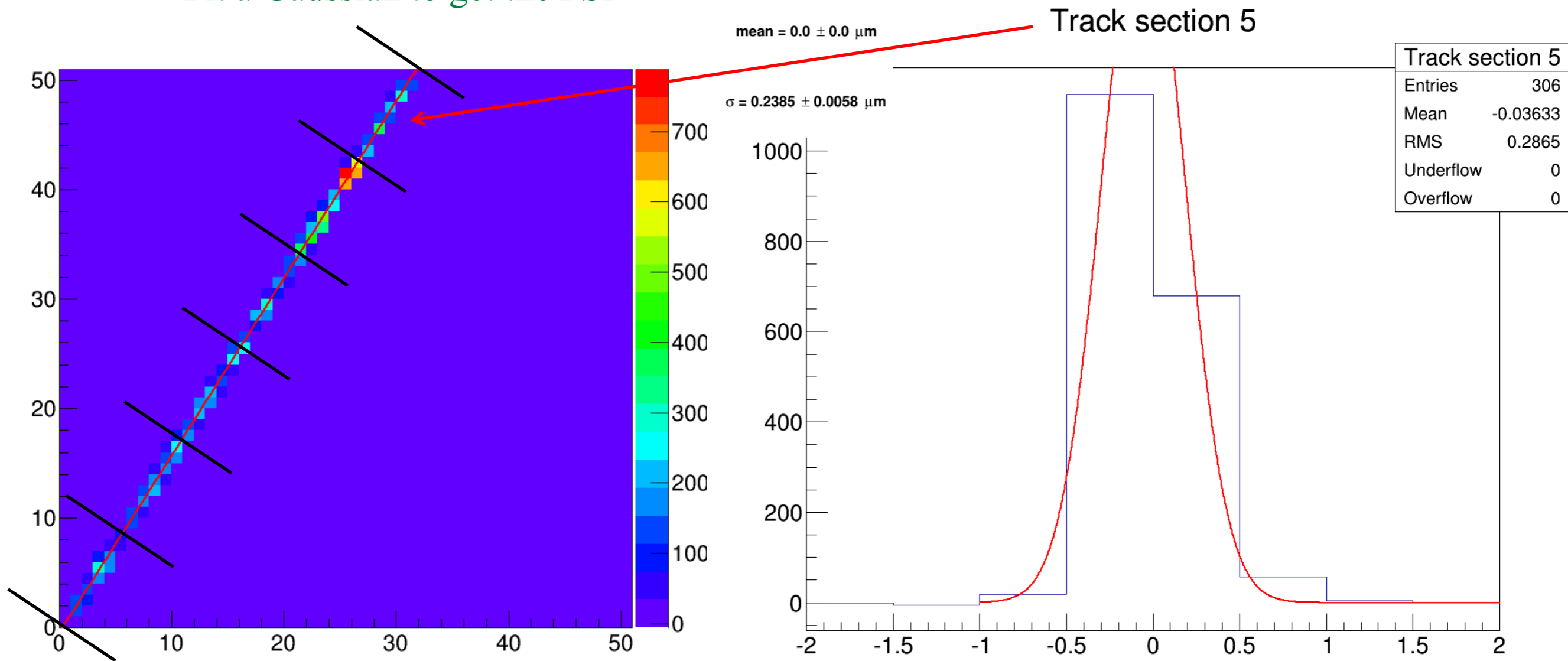| Track section 3	
Entries	306
Mean	0.0788
RMS	0.3694
Underflow	0
Overflow	0

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Segment Measurement

- Fit each track with straight line
  - Divide track into n segments
  - For each segment:
    - Produce histogram of intensity as a function of distance to the track
   - Fit a Gaussian to get the PSF

Segment Measurement

- Fit each track with straight line
    - Divide track into n segments
    - For each segment:
        - Produce histogram of intensity as a function of distance to the track
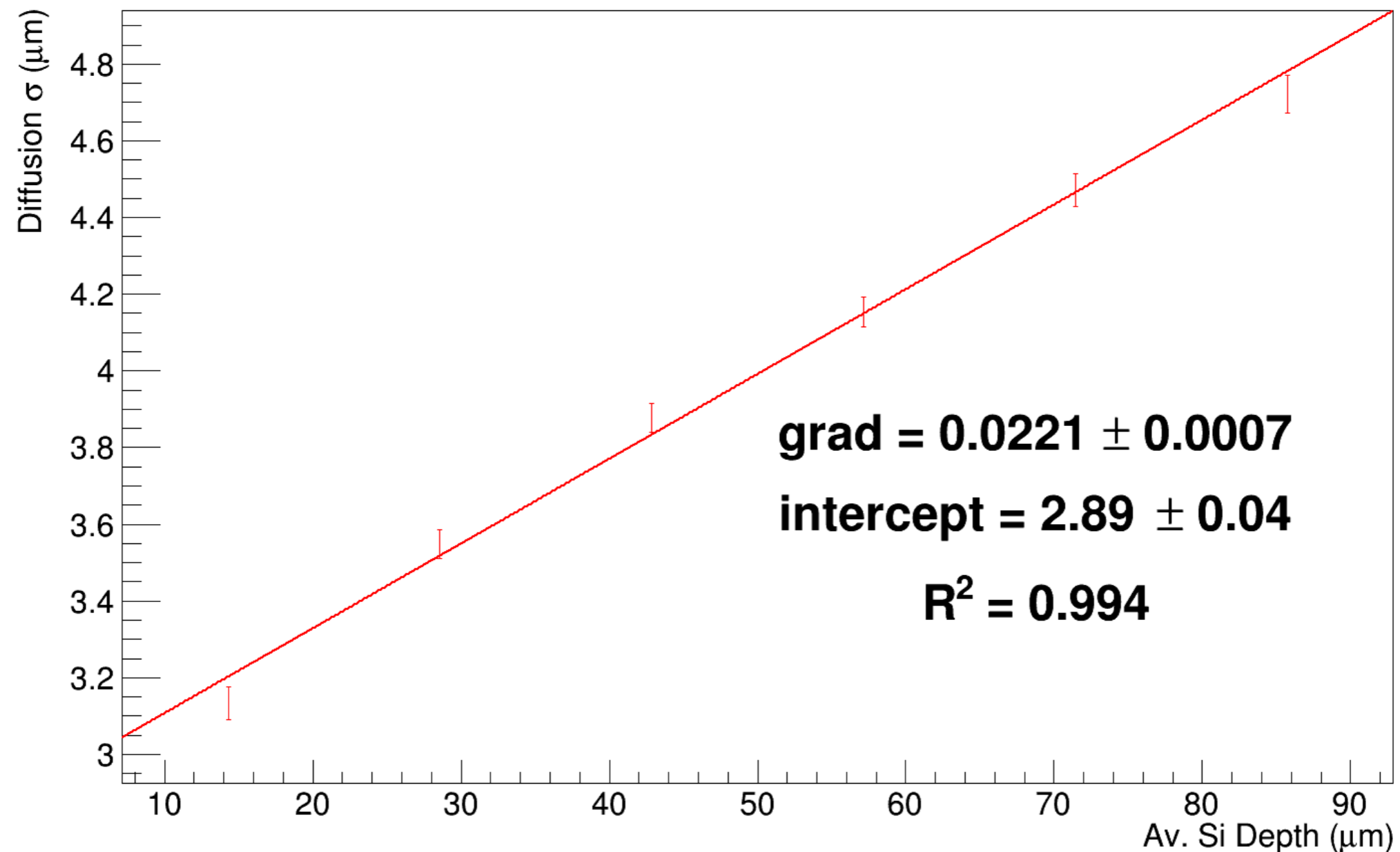   - Fit a Gaussian to get the PSF

Diffusion Measurement

- ‣ Plot the widths of these Gaussians w.r.t. track segment number
- ‣ Fit a straight line to determine the orientation (directionality) of the track
- ‣ If gradient is positive – leave as is
- ‣ If gradient is negative – reverse order
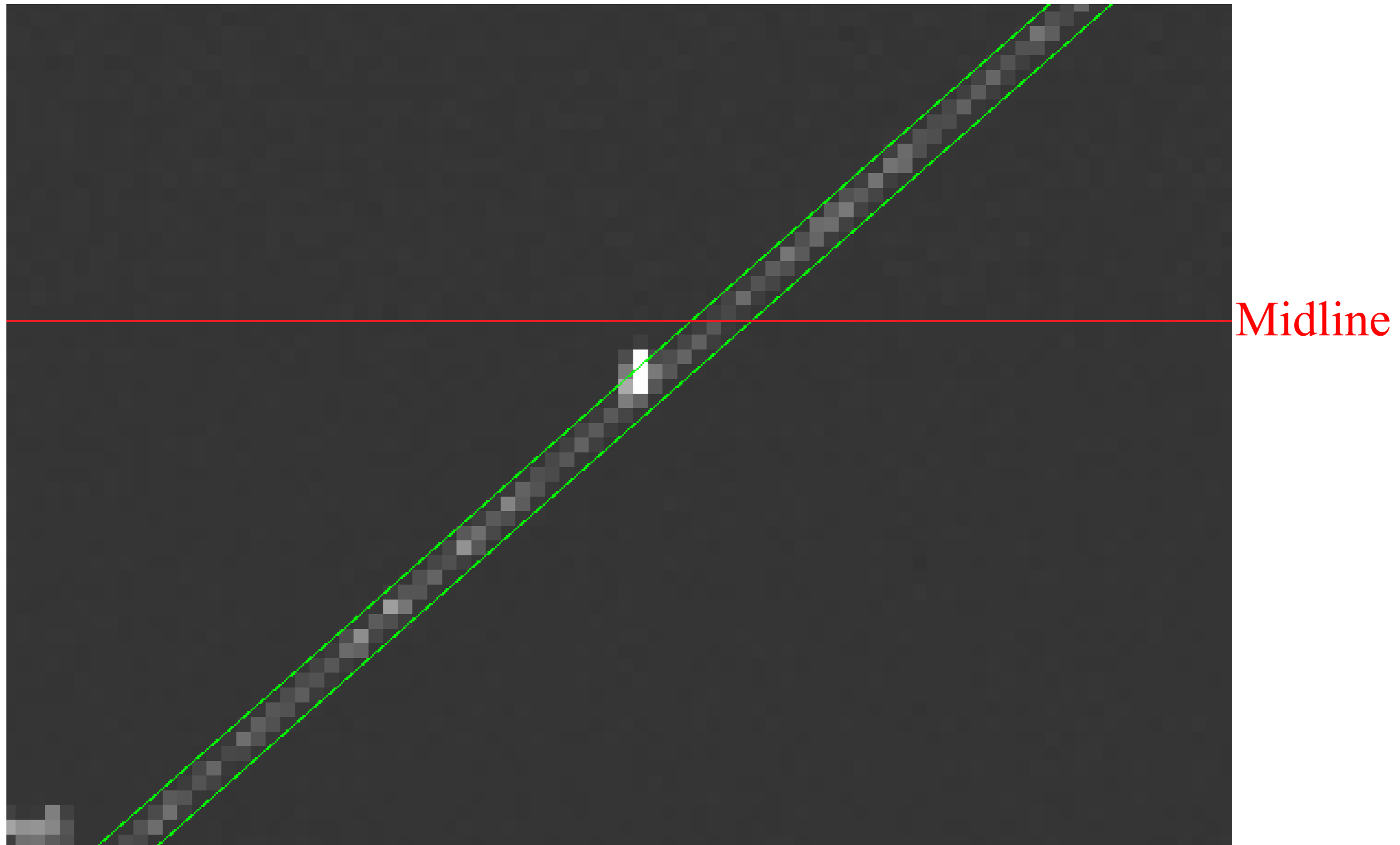 - ‣ tracks are now aligned w.r.t sensor surface
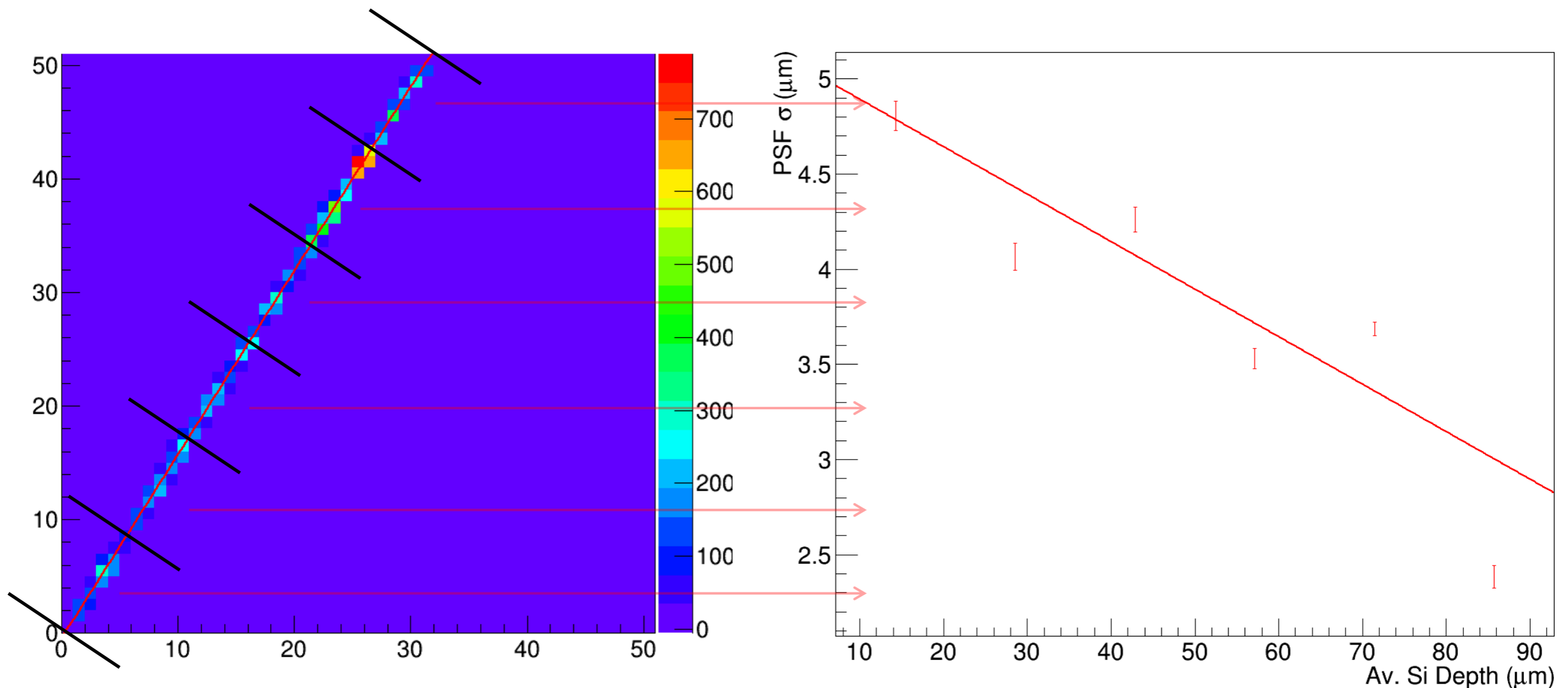
Diffusion Measurement

‣ Average all tracks segment PSFs together

‣ Plot these average PSFs as a function of (averaged) depth in silicon

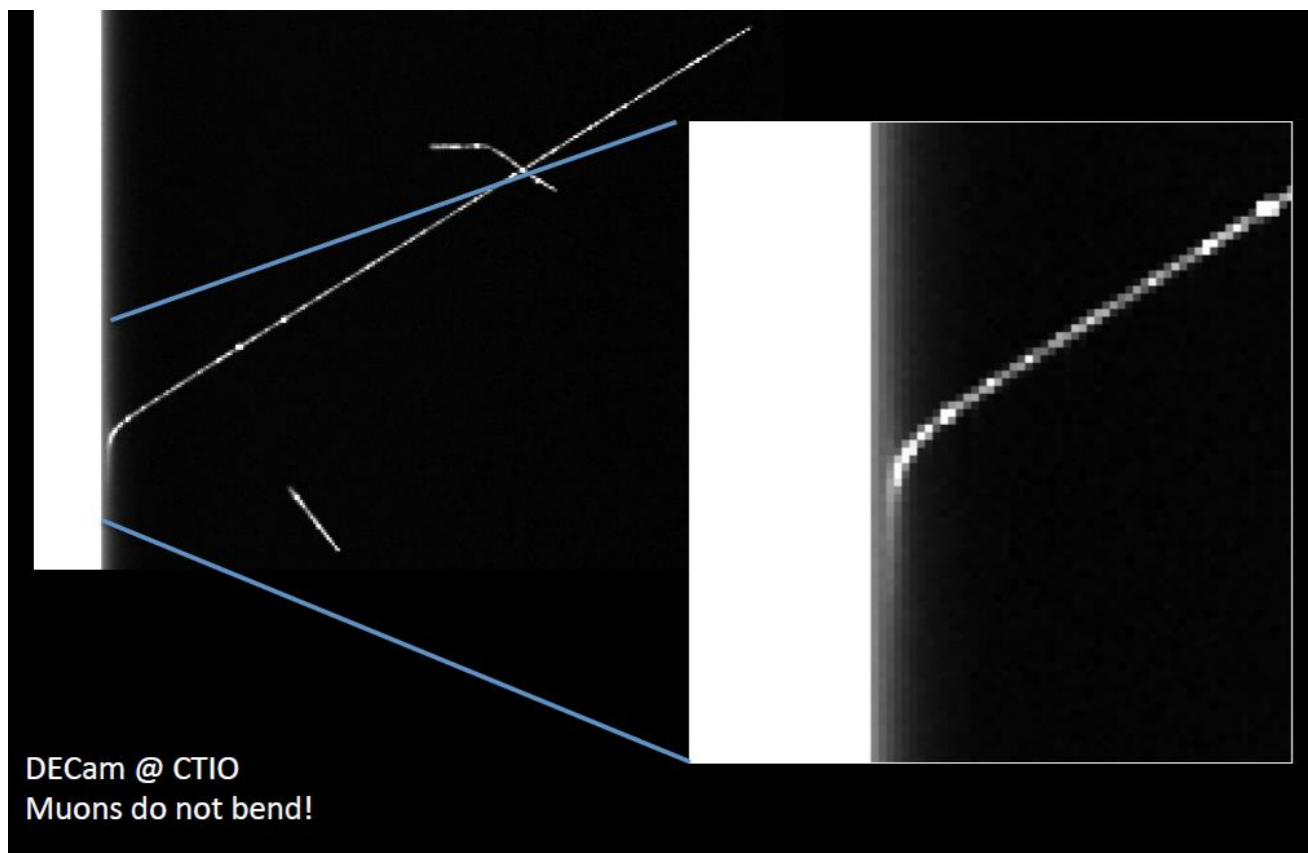 ‣ → Get diffusion as a function of depth in silicon
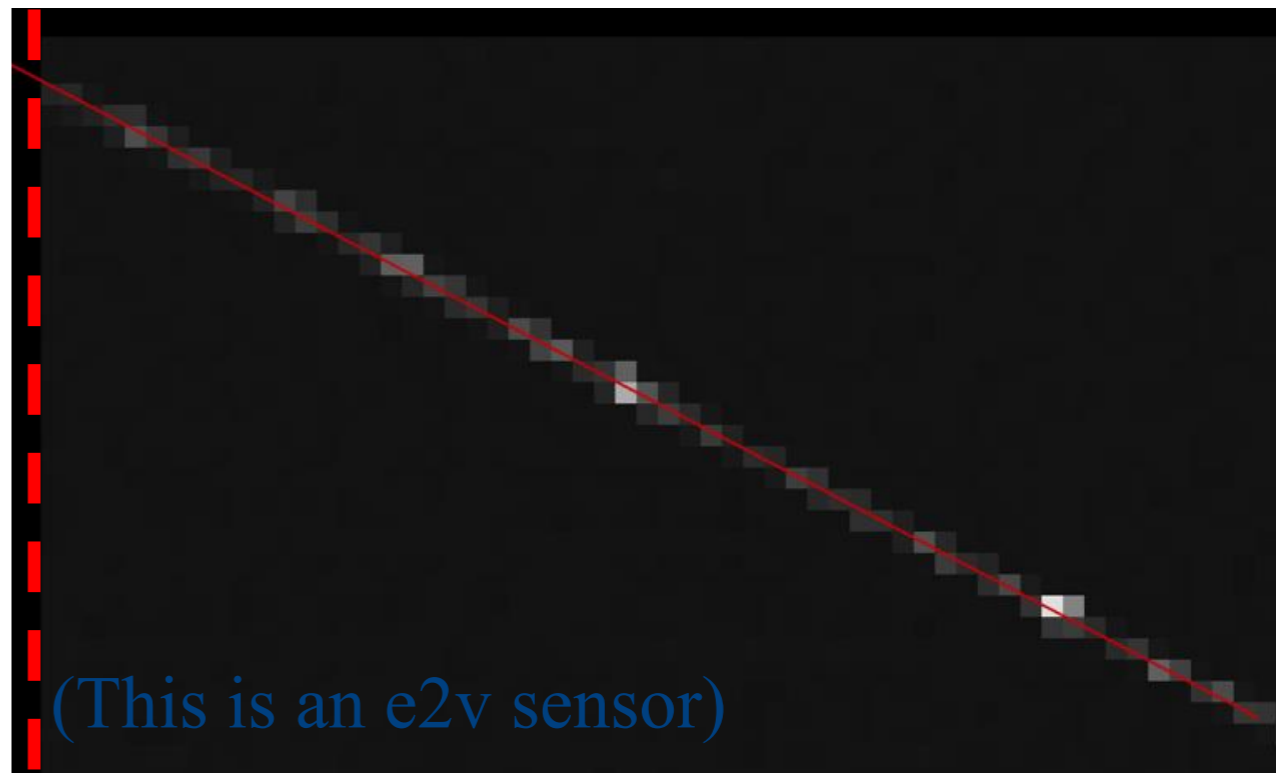
Midline bending

‣ Midline (not) bending:

Midline

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Edge Bending

DECam muon track

DECam @ CTIO
Muons do not bend!

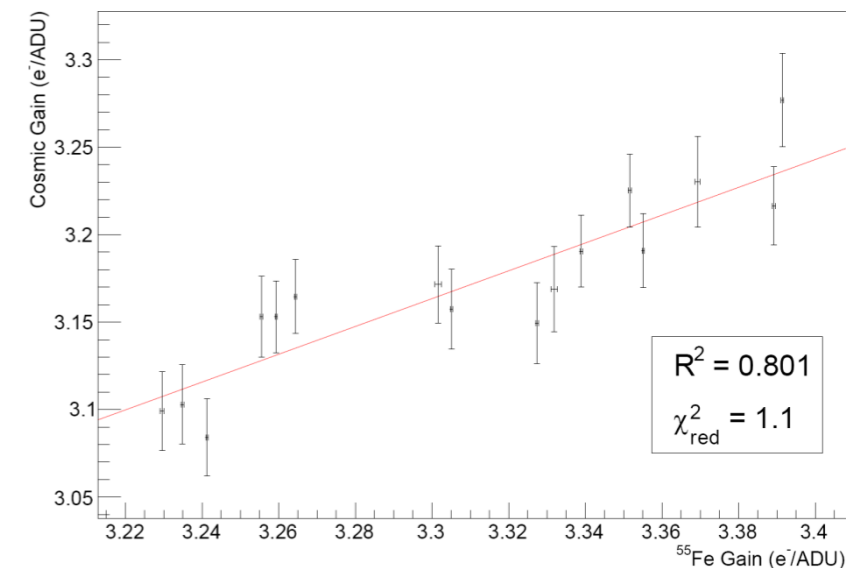## LSST muon track

(This is an e2v sensor)

Sensor edge

DECam edges both glow *and* **bend** ☹

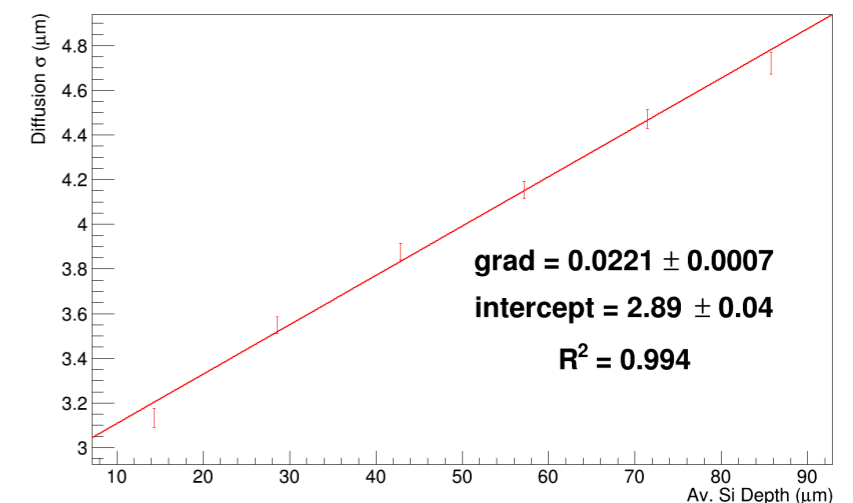LSST edges neither glow *nor* **bend**! ☺

Sensor characterisation

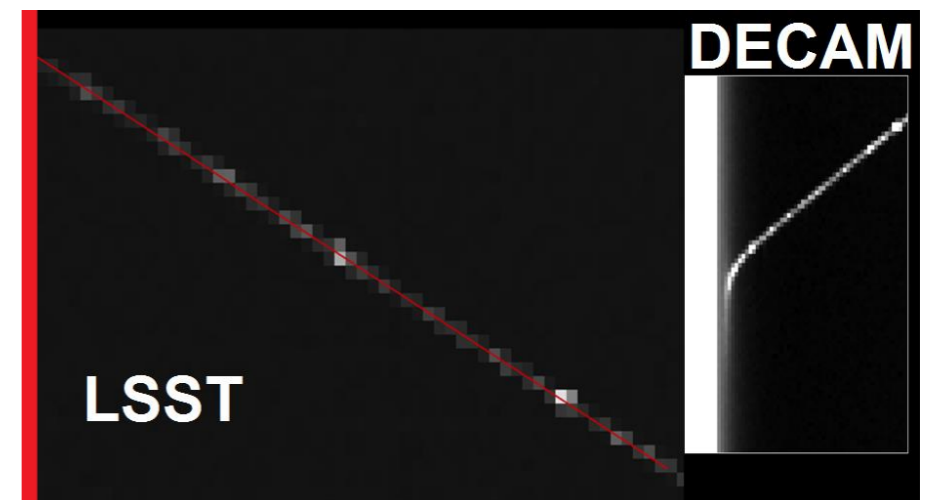‣ **Gain measurement with cosmics** ⟶

  ‣ Comparison with ^{55}Fe

‣ **Diffusion measurement**

  ‣ PSF found to increase with distance to collection electrode

  ‣ Quantitative analysis to follow

‣ **Cursory look at edge effects** ⟶

  ‣ LSST sensors seem to distort much less than DECam

Sensor characterisation

‣ Many thanks to:

- Paul O'Connor & Ivan Kotov for the data

- Robert Lupton & Paul Price for their help with DMStack

‣ Any questions?